

**STUDY
OF
RUBBER - TIRED TRANSIT
TECHNOLOGY**

**HONOLULU RAPID TRANSIT PROJECT
PRELIMINARY ENGINEERING & EVALUATION PROGRAM
PHASE II**

**DEPARTMENT OF TRANSPORTATION SERVICES
CITY & COUNTY OF HONOLULU**



DANIEL, MANN, JOHNSON, & MENDENHALL

TECHNICAL REPORT

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TRANSIT TECHNOLOGY

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PHASE II

Prepared For

DEPARTMENT OF TRANSPORTATION SERVICES

CITY & COUNTY OF HONOLULU

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I. INTRODUCTION

This Technical Report contains the results of a study of rubber-tired transit technology for application to the proposed rapid transit system in Honolulu. The study included a survey through visits to operating transit properties, transit equipment manufacturers, test track facilities, and research organizations in the United States, Canada, Mexico, and Japan.

A preliminary evaluation of various transit vehicle systems was accomplished in 1971 as part of the ongoing planning for the Honolulu Rapid Transit System. That evaluation (reported in Reference 1) concluded that "the trunk line vehicles should be intermediate-sized, lightweight, pneumatic-tired transit cars operating as trained units on fixed guideways." Since considerable research, development and operational experience had been accomplished on rubber-tired transit vehicles in the interim since the 1971 study, the survey described in this report was conducted to update knowledge on the current state-of-the-art and proposed developments in the field, to provide a solid technical base for further definition of the trunk line portion of the Honolulu system.

While the survey emphasized the characteristics of the vehicle/guideway interface, much information was gathered on other applicable subjects; where pertinent, this information is included in the report. The survey encompassed a wide range of vehicle sizes, since some of the subsystem component technologies for smaller systems could have application for larger vehicles. In particular, data was obtained on the Japanese CVS System, a small, four-passenger, collector-distributor type network system not directly applicable for trunk line application.

The transit systems included in the survey (summarized in Table I-1) collectively represent the current and near-term state-of-the-art available. While there is some on-going work on rubber-tired systems in Europe, the technology development there is no more advanced than that in North America and Japan.

Chapter II of this report describes the survey itself, and Chapter III details the information collected. Chapter IV summarizes some of the more important findings of the survey and the results of the evaluation made of the guidance/switching systems applicable to the Honolulu system.

TABLE I-1
SUMMARY OF RUBBER-TIRED TRANSIT SYSTEMS

SYSTEM OR MANUFACTURER	MODEL	LOCATION	VEHICLE DIMENSIONS (Ft)			VEHICLE DESIGN CAPACITY (Number of Passengers)			VEHICLE WEIGHT (Lbs)		HEADWAY (Sec)		LINK CAPACITY PER VEHICLE (Passengers per Hr)		MAXIMUM OPERATING SPEED (mph)	TIRES PER VEHICLE (Number)	DIAMETER OF TIRES (Inches)	GUIDANCE ^d (Type)	SWITCHING ^e (Type)	DEVELOPMENT STATUS	
			L	W	H	Seated	Standing	Total	Empty	Gross	Nominal	Minimal	Nominal	Peak							
1.	BENDIX-DASHAVEYOR	Family 2	Transpo 72 ^a	42.0	9.0	10.5	40	50	90	24,000	37,500	—	15	—	21,600	60 0	8	37 Foam	OSA	VT	Test Track
2.	BENDIX-DASHAVEYOR	Animal Domain Ride	Toronto	28.0	7.3	10.2	40	0	40	19,200	26,000	240	120	600	1,200	20	4	42 Pneumatic	OSA	VT	Under Construction
3.	BOEING	Morgantown	Morgantown, West Virginia	15.5	6.7	8.75	8	13	21	8,750	11,900	—	7.5	—	1,080	30	4	Dual Chambers	OSW	OBF	Test Track
4.	FORD ACT	El Paso/Juarez	El Paso/Juarez ^b	42.0	8.7	9.0	36	36	72	30,000	50,000	Shuttle	Shuttle	Shuttle	Shuttle	40	8-16	—	OSA	OBF	Design Development
5.	FORD ACT	Fairlane	Dearborn, Michigan ^b	24.8	6.7	8.7	10	14	24	16,800	18,900	10	6	8,640	14,400	30	4	28 Foam	OSA	OBF	Test Track
6.	KAWASAKI	KCV-12	—	29.8	7.7	10.3	24	26	50	18,772	26,222	75	—	2,400	—	46.5	—	—	OSA	VT	Concept Only
7.	KAWASAKI	KCV-13	Kobe ^a	20.8	7.7	10.3	14	16	30	9,912	14,412	90	—	1,200	—	40	4	28 Foam/Pneu.	OSA	VT	Test Track
8.	LTV	Airtrans	DFW Airport	21.0	7.0	10.0	16	24	40	14,000	20,000	—	15	—	9,600	17	4	Pneumatic	OSW	OBM	Operational
9.	MEXICO CITY	Metro	Mexico City	56.3	8.2	13.0	40	126	166	56,896	80,229	240	145	2,490	4,120	45	8	Pneumatic	OSA	LR	Operational
10.	MITSUBISHI	MAT	Hiroshima ^a	18.7	7.2	9.5	16	24	40	13,216	19,216	—	90	—	1,600	36	4	32	CGB	VR	Test Track
11.	JAPAN ROLLING STOCK MANUFACTURING CO.	VONA	Toyokawa ^a	19.7	6.6	10.0	11	14	25	10,080	13,380	90	90	1,000	1,000	36	4	28 Pneumatic	CGB	LR	Test Track
12.	NIIGATA ENG. CO.	Newtran	Niigata ^a	23.3	7.5	11.2	20	30	50	15,680	23,180	—	—	2,400	9,000	30	4	Foam	OSW	OBF	Test Track
13.	ROHR CORP.	DMV	None	26.1	8.0	8.8	21	15	36	14,500	19,900	—	11	—	11,781	60	6	31 Pneumatic	OSW	LR	Concept Only
14.	SAPPORO	Metro ^c	Sapporo	88.6	10.1	12.1	82	104	186	73,024	100,924	300	—	2,232	—	45	28	35 Pneumatic	CGB	VT	Operational
15.	TOKYU CAR CO.	Paratran	Yokohama ^a	23.8	7.2	10.3	24	16	40	13,440	19,440	90	—	1,600	—	36	8	26 Pneumatic	IBG	LT	Test Track
16.	WESTINGHOUSE	Transit Expressway	Pittsburgh ^a	30.5	8.7	9.7	28	26	54	19,500	27,600	120	—	1,620	—	70	4	36.6 Pneumatic	CGB	LT	Test Track
17.	WESTINGHOUSE	Satellite Transit System	Seattle/Tacoma Airport	37.0	9.3	11.0	12	90	102	25,500	42,800	100	—	3,672	—	35	8	36.6 Pneumatic	CGB	LT	Operational
18.	WESTINGHOUSE	Tampa Shuttle System	Tampa Airport	36.3	9.3	11.0	0	100	100	21,500	36,500	70	—	5,040	—	26	8	36.6 Pneumatic	CGB	LT	Operational
19.	WESTINGHOUSE	Satellite Transit Shuttle	Miami Airport ^b	38.0	9.0	11.0	0	128	128	30,000	49,200	100	—	1,500	—	30	8	36.6 Pneumatic	CGB	LT	Under Construction

^a Projected.

^b Test Track.

^c Two-Car Articulated Unit.

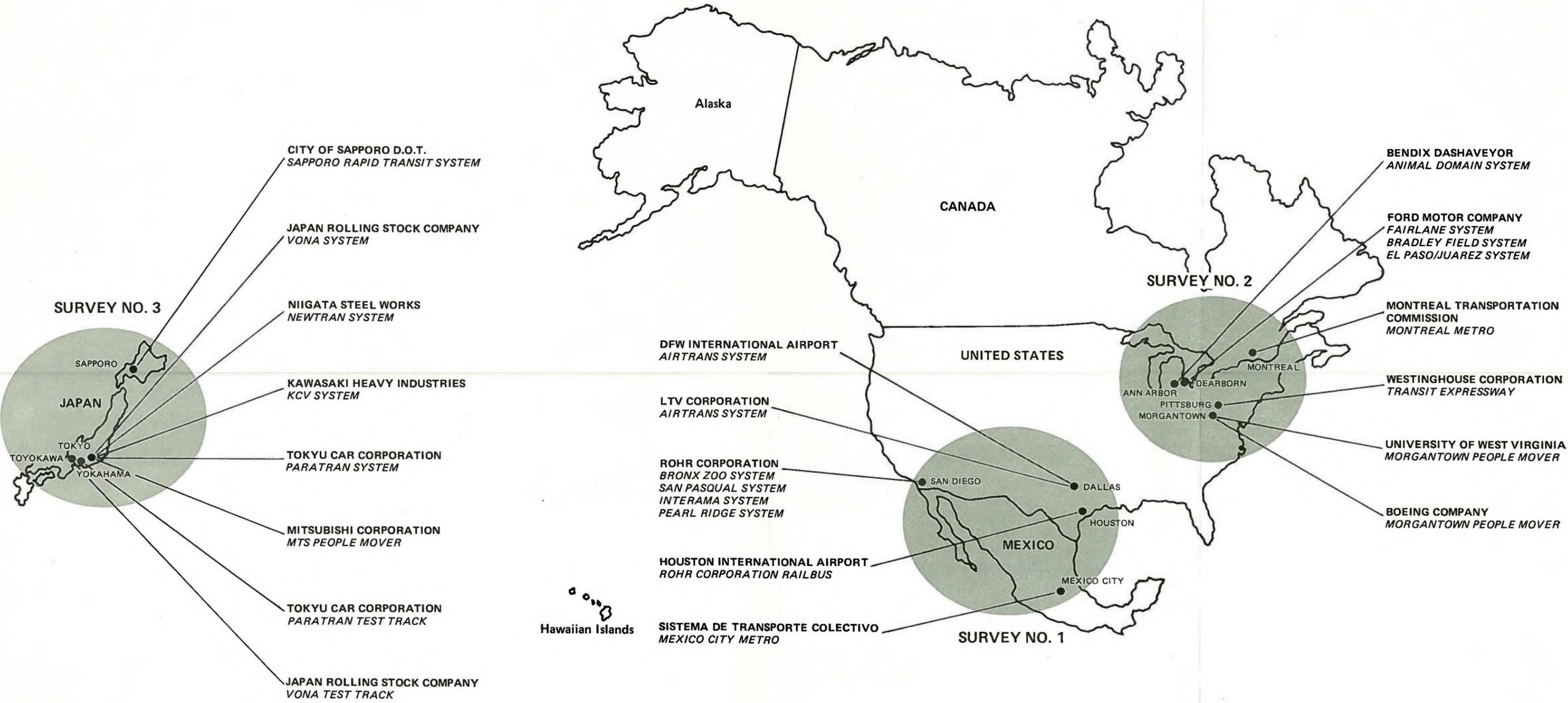
^d OSA — Outboard Steered Axle
OSW — Outboard Steered Wheel
CGB — Center Guide Beam
IBG — Inboard Guidance

^e LT — Lateral Translation of Guide Beams
LR — Lateral Rotation of Guide Beams
VT — Vertical Translation of Guide Beams
VR — Vertical Rotation of Guide Beams
OBF — On-Board Switching with Fixed Guide Beam
OBM — On-Board Switching with Movable Guide Beam

TABLE I-1
SUMMARY OF RUBBER-TIRED
TRANSIT SYSTEMS

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RUBBER TIRED TRANSIT TECHNOLOGY SURVEY LOCATIONS



**RUBBER TIRED TRANSIT TECHNOLOGY SURVEY LOCATIONS
FIGURE II-1**

**TABLE II-1
ELEMENTS OF TECHNOLOGY SURVEY**

SURVEY NO.	LOCATION	AGENCY	SUBJECT		
I	Mexico City, Mexico	Systema de Transporte Colectivo	Mexico City Metro System		
	Houston, Texas	Houston International Airport	Rohr Airport People Mover System		
	Dallas, Texas	LTV Aerospace Corporation	Airtrans System		
	Dallas, Texas	DFW Regional Airport Administration	DFW Airtrans System		
	San Diego, California	Rohr Corporation	"M" Series Transit Systems		
II	Morgantown, West Virginia	Boeing Company	Morgantown People Mover System		
	Morgantown, West Virginia	University of West Virginia	Morgantown People Mover System		
	Pittsburgh, Pennsylvania	Westinghouse Corporation	Transit Expressway System SeaTac Satellite Transit System Tampa Airport Shuttle System Miami Airport People Mover		
			Dearborn, Michigan	Ford Motor Company	Fairlane Transit System El Paso/Juarez Transit System Bradley Field Transit System
					Ann Arbor, Michigan
	Montreal, Canada	Bureau de Transport Metropolitain	Montreal Metro System		
III	Tokyo, Japan	Niigata Steel Works	NTS System		
		Kawasaki Heavy Industries	KCV System Sapporo Transit Vehicles		
	Tokyo, Japan		Japan Rolling Stock Manufacturing Co.	VONA System	
	Tokyo, Japan	Mitsubishi Group	MAT System		
	Tokyo, Japan	Tokyu Development Corporation	Transit and New Development		
	Sapporo, Japan	Sapporo Department of Transportation	Sapporo Rapid Transit System		
	Yokohama, Japan	Tokyu Rolling Stock Manufacturing Co.	PARATRAN System		
	Toyokawa, Japan	Japan Rolling Stock Manufacturing Co.	VONA Test Track		
	Higashi Murayama, Japan	Japan Society for the Promotion of the Machine Industry	CVS System		

III. THE SYSTEMS

BACKGROUND

The characteristics of the various systems surveyed are summarized in Table I-1. This section presents a general description of each of the systems. More detail is presented in subsections on guidance, support, and switching concepts employed in the various systems, and in subsections on noise and ride quality experienced.

For purposes of organization and clarity of presentation, the system capacity spectrum has been categorized into four general classes:

1. High-capacity systems designed to be operated in trains:

Mexico City, Montreal, Sapporo

2. Medium-capacity, U.S.A., systems presently operating in one- or two-car units, but presumably capable of trained operations:

Westinghouse Systems, LTV Airtrans, Bendix Dashaveyor Systems, Rohr "M" Series, Ford ACT Systems, and Boeing Morgantown

3. Medium-capacity Japanese systems as in Category 2 above:

Niigata Newtrans, Nippon Sharyo VONA, Tokyu PARATRAN, Kawasaki KCV, and Mitsubishi MAT

4. Small (two- to six-passenger vehicles) systems for personal rapid transit operations (not further discussed in this report):

CVS, Rohr Monocab, etc.

HIGH CAPACITY SYSTEMS

The three high-capacity, rubber-tired transit systems surveyed are shown on Figure III-1. Although some differences do exist, the Mexico City and Montreal systems are very similar; both were based on the Paris Metro design.

II. SURVEY

Considerable attention was given to the design of the technology survey so that a wide variety of concepts and experience could be reviewed in a cost-effective manner. This entailed a careful review of the geographical location of various operational systems and R&D programs, and a selection of those matching the system requirements and characteristics of the Honolulu system.

From a requirements standpoint, a preliminary set of nominal requirements and characteristics had been established for the Honolulu System through previous planning and analysis (Reference 2) as follows:

1. LINE CAPACITY - 25,000 to 30,000 passengers per hour (350,000 per day)
2. MAXIMUM GUIDEWAY GRADIENT - 6 percent sustained grade
3. MAXIMUM SPEED - 60 mph
4. ACCELERATION-DECELERATION - Up to 3.3 mphps
5. MINIMUM EXTERIOR VEHICLE NOISE
6. LIGHTWEIGHT VEHICLE TO MINIMIZE GUIDEWAY STRUCTURE AND ENERGY REQUIREMENTS
7. CAR SIZE - Approximately 40 feet long to accommodate 70 total passengers (about half seated)
8. HEADWAY - Approximately 90 seconds

In recent years, rubber-tired transit system R&D has seen much impetus, and such systems for line-haul and people mover applications are in operation or under development in many areas of the world. These systems and developments were reviewed as part of the process of establishing the sites to be visited during the technology survey.

The nature of developments in North American and Europe was fairly well known. However, not much was known about the activity in Japan, but occasional bits of information indicated the possibility of considerable development there. A preliminary survey by DMJM's Tokyo office confirmed this assessment, revealing the existence of several medium-capacity, rubber-tired transit system programs.

In addition to the requirements and geographical considerations, including several types of visits in the survey was desirable. For example, certain types of information become available only through considerable operational history. Tire life and maintenance problems would fall into such a category. Therefore, to include visits to transit properties with considerable revenue operation history was important. Also considered desirable was that the investigators be able to obtain first-hand experience in assessing the characteristics of the systems. Therefore, visits to operational test tracks needed to be included in the survey. To assess the future course of development of rubber-tired transit was also desired. For this reason, visits to manufacturers and research agencies, where concept development and R&D were underway, were deemed advisable. Finally, it was seen that many subsystem technologies of importance existed on systems that were not directly applicable to the Honolulu problem, but had potential of being adapted to Honolulu requirements by minor modification or evolution. An attempt was made to include such circumstances in the survey.

With all the above criteria in mind, a three-part survey plan evolved which, it was felt, satisfied all of the survey objectives in an efficient manner. The geographical locations of the survey sites are arrayed on Figure II-1, and the elements of the survey are delineated in Table II-1. Survey No. 1 covered the southern portion of the United States and Mexico City; Survey No. 2 covered the northern portion of the United States and Montreal; and Survey No. 3 covered Japan. With the comprehensive group of rubber-tired transit technologies included in these survey areas, the inclusion of Europe in the survey was not felt to be warranted. The surveys were conducted during May, June, and July of 1974, with some subsequent follow-up investigations.

During the various visits, discussions were held with management, technical, operating, and maintenance personnel. Considerable time was spent riding on the operational systems and test tracks to assess the general quality of the experience, as well as ride quality, noise, and other characteristics. Survey type noise measurements were made with a General Radio GR1565-B Sound Level Meter to check published values and to provide data where published values were not available. Numerous photographs were taken to illustrate particular features of each system or technology. These photographs are the basis of many of the illustrations contained in this Technical Report.

In most cases, the agencies and manufacturers visited were very cooperative. All of the manufacturers expressed interest in participating in any procurement bidding process arising out of the Honolulu program and wished to be kept informed as the planning and preliminary engineering progress.

Mexico City Metro

The Mexico City Metro is made up of three uncoupled lines requiring passenger transfer at the resulting node stations. Total combined length of the lines is 40.8 km (25.3 miles). Line No. 2 has 12.6 km (7.8 miles) at surface, leaving a total of 28.2 km (17.5 miles) in tunnel. Because of earthquake problems, the running surface is of steel rather than concrete. This is true of the surface, as well as subway portions of the guideway.

Vehicles are of three types. M cars have cabs and are powered. R cars are powered, but have no cabs. Trailer cars have neither cabs nor power. Trains consist of two M cars, four R cars and three trailers. There are, therefore, six powered and three unpowered cars per train. Each powered car has four motors of 150 hp so that there are 24 motors on each train, totalling 3,600 hp.

The system design and operation are based on two philosophies or ground rules. The first is that there be no operational switches. Where transfers are required, passengers transfer rather than trains. Switches are operated only at the ends of the three lines (with no passengers on board) to transfer trains to the reverse direction trackage. Switches are also available to route trains to the storage and maintenance facilities. During normal operation, the trains do run through switches in the tangent position. The engagement of the steel backup wheels with switch parts can be felt and heard, but the process is not objectionable.

The second philosophy is to provide a motorman on board each train and have him perform most of the operating functions. In essence, then, the system is one of manual operation with automated monitoring for safety.

Currently, the trains operate at a headway of 2 minutes and 25 seconds during peak hour and 4 minutes at off peak. Consist remains the same, and trains are removed to get the longer headways. Future plans call for reducing headway to 90 seconds during peak hour, but a current lack of rolling stock prevents use of this shorter headway now.

The system is now carrying up to 2,300 passengers per train (overloading tires and suspension system). At the current headway of 2 minutes, 25 seconds, this amounts to a link volume capacity of 57,000 passengers per hour. With the headway reduced to 90 seconds and the loading reduced to the maximum crush value of 2,250 passengers per train, the resulting theoretical link volume would be almost 90,000 passengers per hour.

Power control for acceleration is obtained by the simple means of switching the motors from series to series parallel to parallel across the line. This gives a three-step voltage profile rather than a smooth and continuous increase as would be the case with a cam or a chopper control. The steps can be felt during acceleration, much like the shifting of gears in a manual-shift automobile transmission, but this was not particularly objectionable.

Acceleration and braking are controlled manually by the operator. The following nominal values have been established for the system:

	<u>Acceleration</u> (mph/sec)	<u>Braking</u> (mph/sec)
Normal 0-48 mph	1.6	2.5
Emergency 6-18 mph	3.0	5.0

Maximum speed for the system is 45 mph, maintained by the operator. If he exceeds this speed by more than 3.5 mph, an automatic over-ride safety device will bring the train to a stop. Specification station dwell times are 10 seconds minimum and 30 seconds maximum, manually controlled by the operator (the doors are opened automatically when the train stops, and closed manually by the operator who looks back down the platform from a door in his cab and actuates the door closing cycle by pressing a button). The operator is supposed to keep track of his dwell times and try to maintain an average of 17 seconds for proper motor cooling. However, stopwatch timing of many stops revealed that the time interval from initiation of door opening to the starting of the train varied from about 8 seconds to 18 seconds, with an average of about 12 seconds. The ability of an operator to control and minimize dwell time, matching it to the needs of the situation at each stop, was impressive.

In general, the system appears now to have obtained a level of quite high reliability by use of a preventive maintenance program. The following programmed vehicle maintenance schedule has been established:

Minor Overhaul	200,000 km (120,000 miles)
Medium Overhaul	300,000 km (180,000 miles)
Major Overhaul	400,000 km (240,000 miles)

As a result, the system is experiencing a minimum of unscheduled maintenance.

The maintenance facilities are quite large, comprehensive, and impressive. During major overhaul, the trucks are separated from the vehicle body, and the vehicle body is stripped down to its "bare bones." The trucks are completely disassembled; then the entire vehicle is reassembled, replacing all worn parts and components in the process.

Since the vehicles are now overloaded, the Metro has more trains on order. When these become available, headways can be reduced to alleviate the overloading of trains.

Planning is under way to provide a light rail vehicle surface system. This will supplement the bus system and help take the load off the subway system.

Montreal Metro

The Montreal Metro is similar to that of Mexico City in most respects. There are, however, some significant differences. In Montreal the running surface is concrete rather than steel. Each nine-car train has a two-man crew - an operator at the front of the train and a conductor at the rear. The main function performed by the conductor is the opening and closing of doors.

The varying elevation of the roadbed permits a portion of the run to be made in coasting mode. This procedure results in a power utilization saving of 10 to 12 percent. The rubber tires were chosen because they allow the grade climbing necessary with this type of operation. In addition, because of the superior adhesion of rubber tires, not all of the axles need to be powered.

Brake shoes are currently made of wood which has been impregnated with peanut oil (Figure III -2). The Metro is not satisfied with the consistency of braking performance provided by this system. In addition, an undesirable maintenance procedure is required. Since it takes a week's operation to seat a shoe for proper operation, and since the life of a shoe is one month, 25 percent of the shoes are replaced each week. This amounts to about 1,000 replacements per week. A special machine (Figure III -3) has been designed to speed the process of attaching new shoes to their retainers. Other materials have been tried for the shoes - for example, the ones made of fiberglass as shown in Figure III -4 - but none has performed satisfactorily.

New subway lines are being constructed in Montreal which will be furnished with a new vehicle design and automated control. With the increased automation, the existing requirement for a two-man train crew will be reduced to an operator only. Train stopping and door opening will be automated.

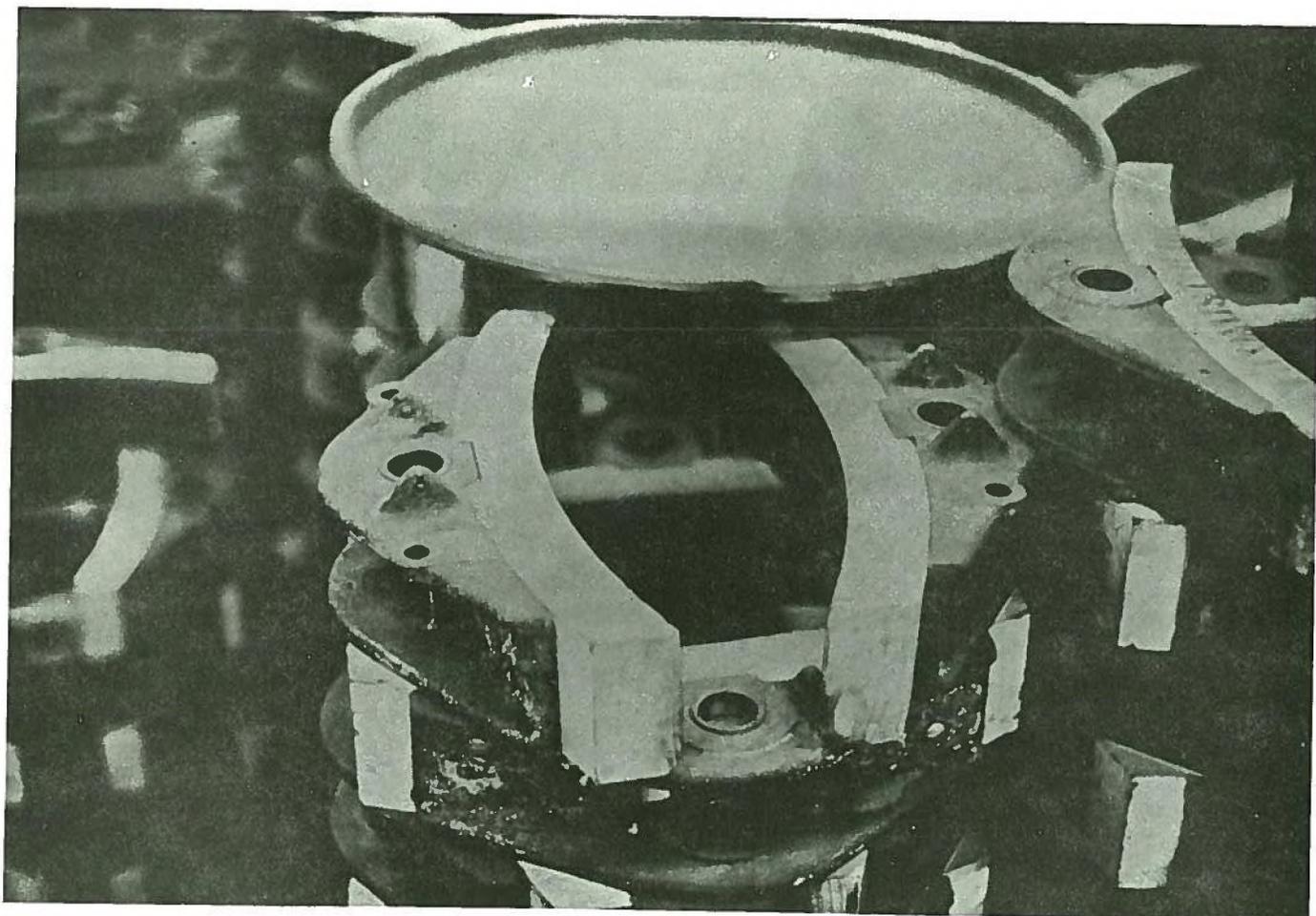


FIGURE III-4 *EXPERIMENTAL FIBERGLASS BRAKE SHOE*

Door closing will remain a manual function to handle the variability in dwell time and to keep the operator alert. An automatic headway control will also be provided. This control will adjust interstation speed to compensate for variations in station dwell time. In addition, it will permit the present minimum headway of 500 feet to be reduced to 150 feet. The new system will also incorporate regenerative braking. Control of power will be changed from a resistance bank system to a chopper control.

Estimated cost for 423 of the new vehicles is \$150 million, or about \$355,000 per vehicle. The old version nine-vehicle train cost \$1.1 million, or about \$122,000 per vehicle.

Sapporo Municipal Rapid Transit Railway System

The urban area under the jurisdiction of the Sapporo Municipal Rapid Transit Railway System is 1,190 sq km (460 sq mi). The existing rail system has a length of 12.6 km (7.8 mi) of which 4.6 km (2.9 mi) are elevated. Additional lines are now under construction so that by 1975 a total of 25 km (15.5 mi) will be in operation. By 1985, the total length of the system will be 45 km (28 mi) for the two uncoupled lines. The existing line will continue to be operated in its present manner with its current equipment concepts. However, due to experience gained in operating the existing line, the new E-W line will incorporate substantial changes.

Physically, the system is quite different from the Mexico City and Montreal Metros. For example, its vehicles are dual units articulated at the center. The hybrid support system has three single-axle unpowered guidance bogies and two dual-axle powered trucks. The guideway, where it emerges to the surface, is completely protected from the weather by a metal and glass enclosure.

Operationally, the current system is somewhat similar to the Montreal Metro since each train has a two-man crew, an operator at the front end and a conductor at the rear. In the new lines, automatic train operation (ATO) will be incorporated, and the conductor will be eliminated. Peak hour demand is 50,000 passengers in each direction. Headway is currently 5 minutes. This will be decreased to 3 minutes for the new E-W line.

Trains perform a switchback maneuver beyond the terminal stations. Time required to perform this maneuver is a potential limit to reductions in headway. The switch concept and its operating experience are fully described in a following portion on switching.

The unique truck and bogie design and its evolution also are described fully in a following portion on support systems. However, one point is worthy of note here. The steepest grade permitted by the Japanese National Railway up to the time of the Sapporo system was 3 percent. Sapporo was able to get special permission to incorporate grades of 4.3 percent by the use of rubber tires.

Sapporo is not satisfied with their current braking system. The braking is neither smooth nor consistent. Braking power from the dynamic brake is dissipated in a resistor. Rubber dust from the tires gets on this hot resistor and, as a result, the entire system has an odor of burnt rubber. The new system will incorporate regenerative braking and a thyristor power control, and better performance is expected from these improvements.

During the 2-1/2 years of operation of the system, no trackage maintenance has been necessary. Their track maintenance crew of two people has had little to do.

Table III-1 provides a comparison of some of the characteristics of the existing system and the revised system.

The Sapporo people are convinced that a rubber-tired system offers considerable savings in required operating personnel. They pointed out that in six Japanese cities with conventional steel wheel systems, 70 to 110 personnel were required per kilometer of system (113 to 177 per mile). For Sapporo the staff is 30 people per kilometer (48 per mile). They also provided the following comparison:

Sapporo	- 1 employee per 210,000 passengers /yr
Osaka	- 1 employee per 100,000 passengers /yr
Nagoya	- 1 employee per 100,000 passengers /yr
Tokyo	- 1 employee per 74,000 passengers /yr

While these figures are impressive, it is likely that at least a portion of the differences is due to factors other than rubber-vs-steel-wheel characteristics. For example, there can be differences in philosophy regarding manpower requirements for equipment and station cleanliness, maintenance, security, etc. Also, the Sapporo system is somewhat newer than the others.

**TABLE III-1
SAPPORO SYSTEM CHARACTERISTICS**

		OPERATIONAL		UNDER CONSTRUCTION	
		N-S LINE		N-S LINE	E-W LINE
Total Length, miles		7.8		1.6	6.6
Service Length, miles		7.5		0.7	6.1
Elevation		subway + elevated		all subway	all subway
Number of Stations		14		2	11
Distance Between Stations, miles		Max.	1.1	0.7	0.8
		Min.	0.3	0.6	0.5
		Avg.	0.6	0.7	0.6
Rolling Stock	No. of Vehicles		72	36	80
	Passengers per Vehicle		90	90	126
	Dimensions (L, W, H), ft		44.3, 10, 11.5	same	59, 10.1, 13.2
	Speed, mph	Max.	43.4	43.4	43.4
		Avg.	19.8	19.8	23.5
Voltage at Power Pickup, dc		750 (3rd rail)	750 (3rd rail)	1,500 pantograph	
Fare Collection	No. of Ticketing Machines		88	63	136
	Added Value Machines		21	7	26
	Money Changers		24	4	26
	Automatic Turnstiles		104	57	145
Control System		CTC-ATC	CTC-ATC	CTC-ATO	
Construction Period		1968-1971	1973-1975	1972-1975	
Cost, \$	Total		248,730,000	72,073,000	280,395,000
	Per Mile		19,585,000	28,789,000	25,167,000
Date of Operations		Dec. 1971	Nov. 1975	Nov. 1975	
Passengers per Day		190,000	49,000	204,000	

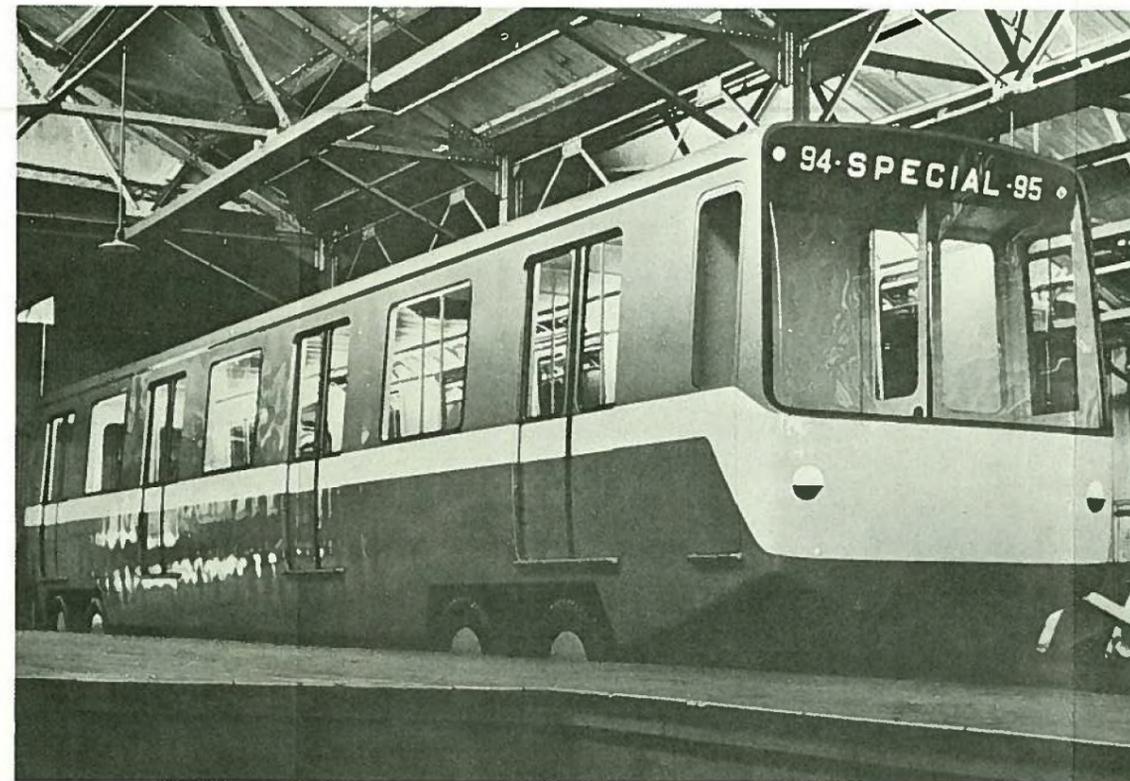
HIGH CAPACITY SYSTEMS CANADA, MEXICO, JAPAN



MEXICO CITY METRO MEXICO CITY, MEXICO



SAPPORO RAPID TRANSIT SYSTEM SAPPORO, JAPAN



MONTREAL METRO MONTREAL, CANADA

MEDIUM-CAPACITY SYSTEMS, U.S.A.

Major examples of the medium-capacity systems surveyed in the United States are shown on Figure III-5. These, and related systems by the same manufacturers, are currently in various stages of evolution from concept development, through design development and test track operation, to full service operation. These systems are presently used for a lower level of service application than is contemplated for Honolulu and probably could not be applied directly. However, most of the subsystem technologies are directly applicable, requiring from minor to medium levels of development to satisfy the Honolulu requirements. These same comments are applicable to the medium-capacity Japanese systems which will be covered later in this section. A summary of the characteristics of all these systems is presented in Table I-1 of Section I.

The Westinghouse Transit Expressway

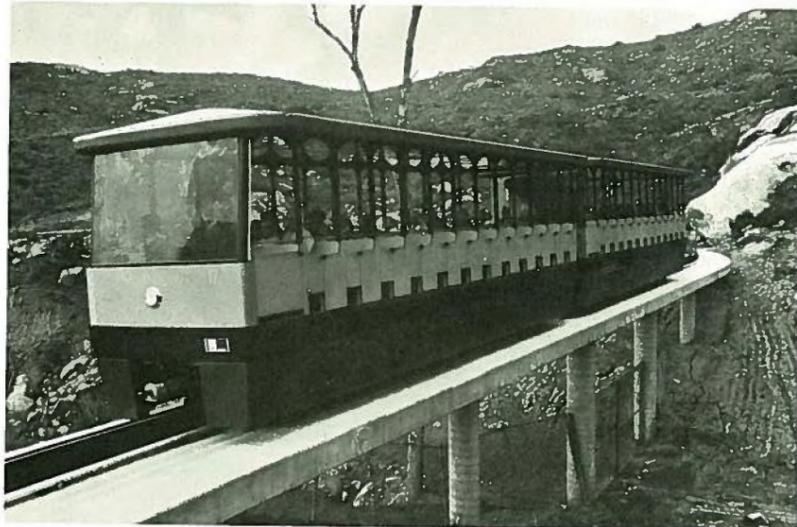
The Westinghouse Transit Expressway illustrated on Figure III-5 is the prototype forerunner of several Westinghouse systems. Two of these, the Seattle/Tacoma and the Tampa systems, are in full public operation. A system for the airport in Miami is currently under construction. These are low speed (25 to 30 mph) systems intended for short distance circulation service in major activity centers such as airports. The basic characteristics of the systems have been published in many brochures and papers and will not be repeated here.

The Sea-Tac system was visited in November, and information was gathered on its operation. The system has demonstrated a high degree of reliability, with an average downtime of less than 6 minutes per day (downtime is defined as an occasion when one vehicle does not depart or arrive at a given station on schedule). The specified average downtime was 10 minutes; the system is also exceeding its specifications for mean time between failures.

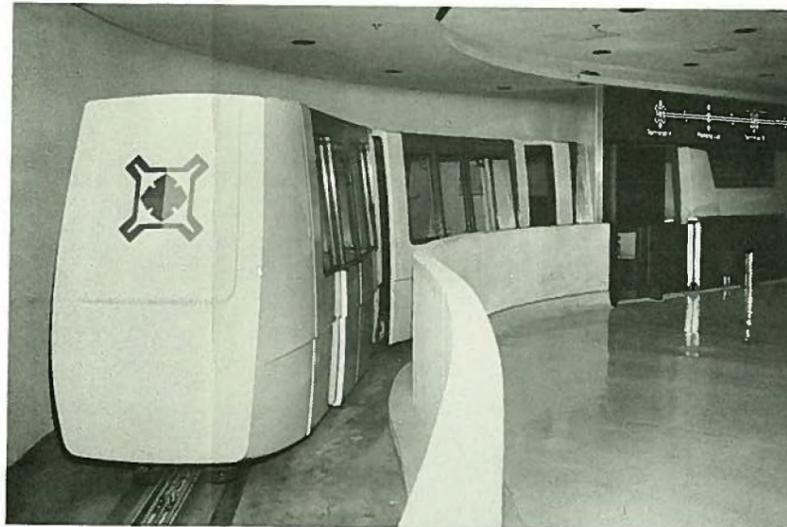
Bendix Dashaveyor Transpo '72

The Bendix Dashaveyor Transpo '72 system shown on Figure III-5 is also a prototype of revenue systems that were to be developed. (Bendix recently decided to suspend their Dashaveyor system development.) This is representative of the company's Family 1 system, with vehicles about 28 feet long. A Family 2 system, with vehicles about 40 feet long, is now being built for the Toronto Zoo (Figure III-5) and will be known as the Animal Domain Ride. A prototype of this system is scheduled to begin testing in late September 1974, at speeds up to 30 mph. Family 2 type systems have

MEDIUM CAPACITY SYSTEMS — U.S.A.



SAN PASQUAL WILD ANIMAL PARK ROHR CORPORATION



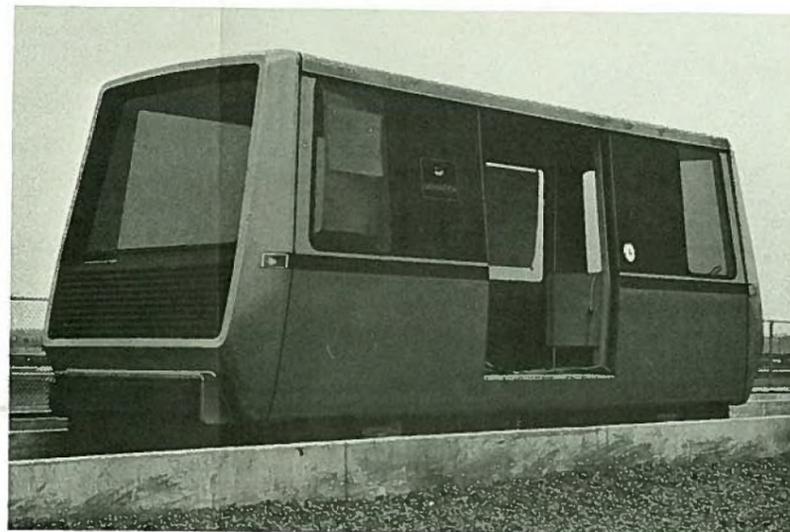
HOUSTON AIRPORT ROHR CORPORATION



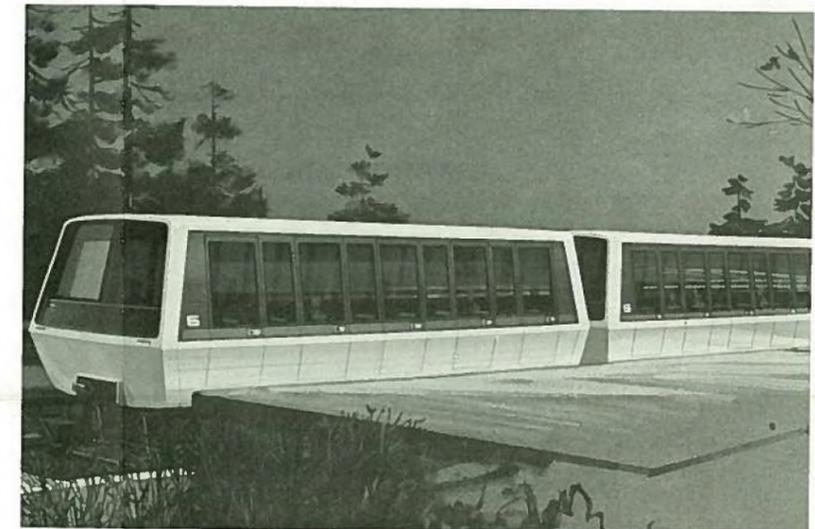
TRANSIT EXPRESSWAY WESTINGHOUSE CORPORATION



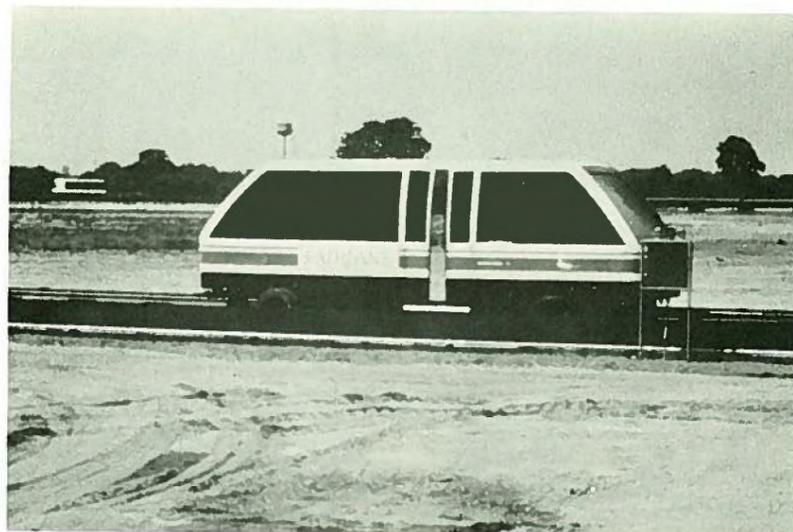
DFW AIRTRANS LTV CORPORATION



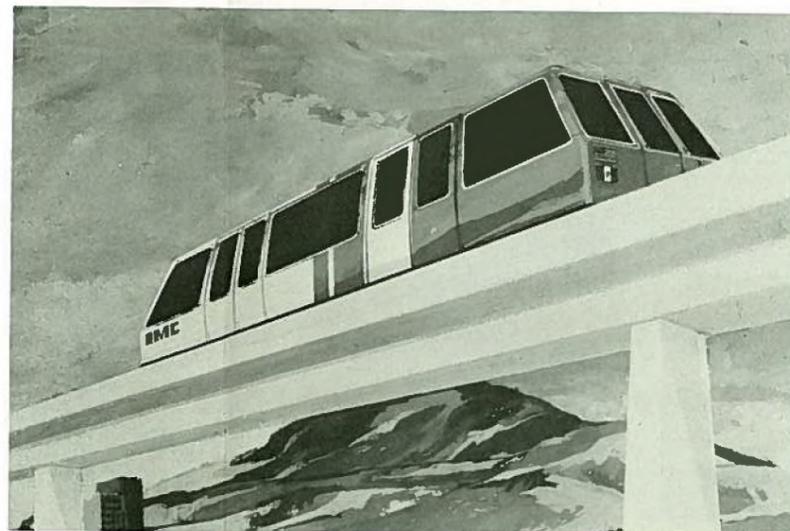
TRANSPO 72 BENDIX/DASHAVEYOR



TORONTO ZOO BENDIX/DASHAVEYOR



FAIRLANE FORD MOTOR COMPANY



EL PASO/JUAREZ FORD MOTOR COMPANY



MORGANTOWN BOEING COMPANY

also been proposed for Interama in Florida and for the Newark Airport in New Jersey. Bendix Dashaveyor had also identified a Family 3 category of systems with vehicles about 12 feet long, but this category was not under active development.

Boeing Morgantown

The Boeing Morgantown system shown on Figure III -5 is intended to operate as a combined transit-mode and demand-actuated system. The transit mode is initiated during peak periods when the capacity in the demand-actuated mode is insufficient to handle the demand. At off-peak hours, the system operates as a true PRT. This duality in operational mode required that a compromise be made in the vehicle size. The 21-passenger capacity is much too large for optimum PRT type operation, whereas a somewhat larger vehicle would probably be more optimal for the transit mode of operation. No actual operation was observed since, at the time of the survey, the entire system was shut down for an extended period of time for vehicle modifications and for installation of a control center and maintenance facility. However, a Morgantown vehicle was observed and ridden in operation at Boeing's test track near Seattle.

Rohr Corporation

The Rohr Corporation has installed about 15 systems in revenue operation, but all of them are relatively low speed systems - 20 mph or less. These (designated as Series M) have been applied to relatively short distance, concentrated activity center, circulation applications and are not intended as primary urban mass transit systems. A typical example of this class of Rohr system is the San Pasqual Wild Animal Park people mover pictured on Figure III -5. Their work on medium-capacity, intermediate-speed systems (40 to 60 mph) is currently in the conceptual and design development stages. An example of such a conceptual system is Rohr's DMV concept, the characteristics of which are presented in Table I-1.

Ford Motor Company

The Ford Motor Company has entered the transit field with its ACT (Automatically Controlled Transportation) series of vehicles. The initial version of this series was the system displayed and operated at Transpo '72. This system has evolved into the Fairlane, El Paso Juarez, and Bradley Field applications. The Fairlane version (Figure III -5) has been undergoing test evaluation and development on Ford's new Cherry Hill test track since early June 1974. The vehicles for Bradley Field will be very similar to the Fairlane vehicles. A rendering of a possible version of the El Paso/Juarez vehicle is shown on Figure III -5. This system is currently in the

conceptual definition stage. Approximate information on its currently defined characteristics is contained in Table I-1, along with summary information on the Fairlane system.

LTV Corporation Airtrans

The LTV Corporation Airtrans system, as currently installed at Dallas / Fort Worth Regional Airport (Figure III-5), combines the movement of passengers, employees, mail, cargo, and waste on a single system, although different vehicle bodies and station arrangements are provided for the various functions.

The LTV Airtrans systems was partially operational when visited, providing passenger, mail, and trash service. The baggage transfer service was not yet operating, and not enough passenger cars were yet available to provide employee service. The target date for acceptance of the system was July 1; LTV was optimistic about meeting the date, but airport personnel were skeptical.

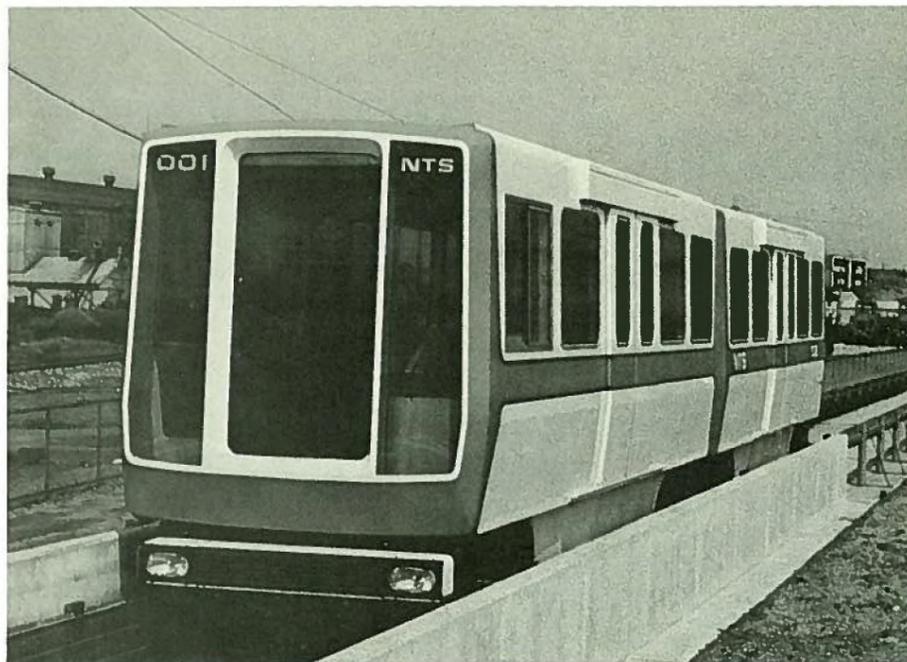
There have been many problems with the system, particularly with the control system software and with the many close operational tolerances. In fact, LTV conceives of a significant part of its current task as being to "loosen up" the system so that it can operate without the excessive Class 1, or disabling, failures now being experienced. To this end, more than 700 detail changes are being incorporated in each vehicle. The passenger vehicles are now operating automatically, but the utility (mail, trash, freight) vehicles were still operating with an on-board operator until more "bugs" could be eliminated from the system.

Questions regarding LTV's future plans revealed that they are eager to apply the experience they have gained to the design of larger transit systems; they view the proposed Honolulu Rapid Transit System as one of the prime potential markets. They are not committed to fully automatic controls if an operator is to be aboard the train, they feel that he should be given major responsibilities for the operation of the train.

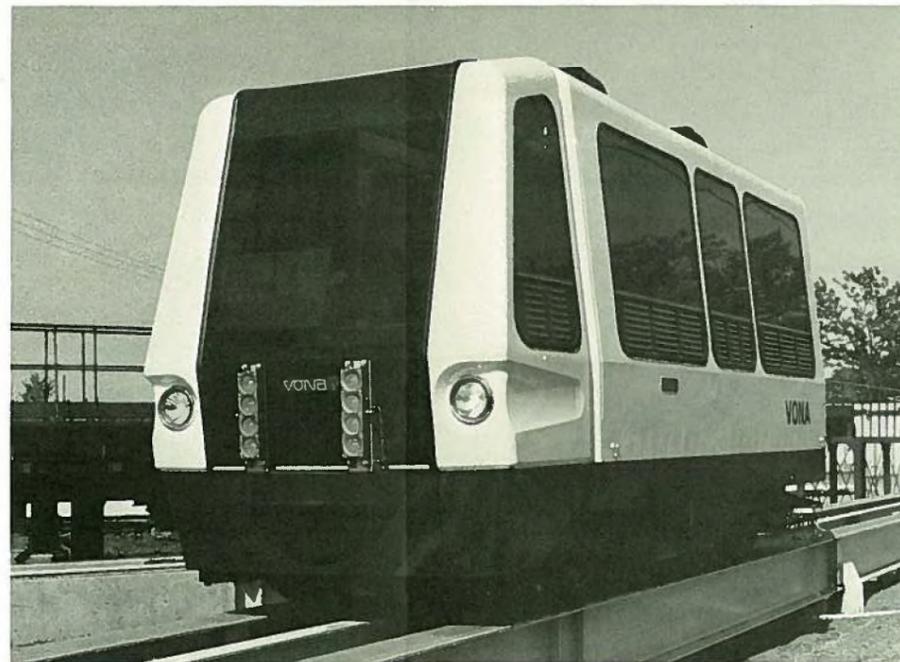
MEDIUM-CAPACITY JAPANESE SYSTEMS

Of particular interest in the survey of Japan are the medium-capacity rubber-tired systems (Figure III-6) being developed as the result of an ongoing competition sponsored by the Japanese Government. Five teams of Japanese firms from the transit equipment industry, supported by electronics and other firms, have been engaged in this program since 1972. The 3-year,

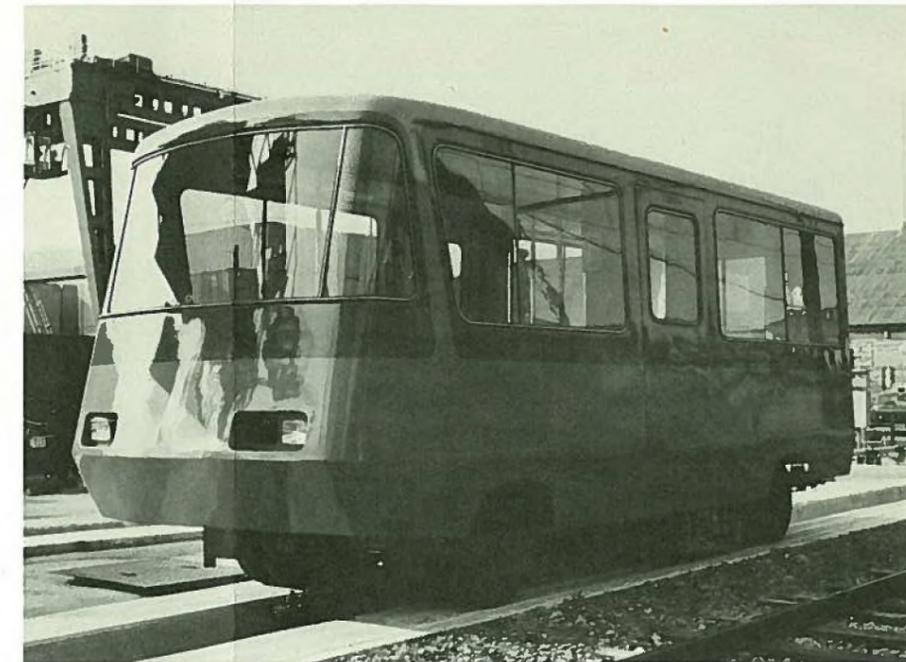
MEDIUM CAPACITY SYSTEMS JAPAN



NEWTRAN, NTS
NIIGATA ENGINEERING COMPANY



VONA
VEHICLE OF NEW AGE
JAPAN ROLLING STOCK MANUFACTURING CO.



PARATRAN
PUBLIC AUTOMATED RAPID TRANSIT
TOKYU CAR CORPORATION



KCV
KAWASAKI COMPUTER-CONTROLLED VEHICLE
KAWASAKI HEAVY INDUSTRIES



MAT
MITSUBISHI AUTOMATIC TRANSPORTATION
MITSUBISHI CORPORATION

Phase I portion culminates by the end of 1974 in the selection of two of the systems to proceed into the next phase. These teams have all progressed to the point where they have test tracks in operation for their systems, including at least one switch and fully automatic operation. The system that survives this competition will be the one to be implemented and installed at various sites within Japan and, of course, will be available for export. The other four systems will be available for export only if their sponsoring companies are willing to proceed with their own funds.

As mentioned, these systems are being developed by teams of firms. Typical of such teams is the one developing the NEWTRAN system. Sumitomo Shoji, a large Japanese trading company, is the Program Manager. Niigata Engineering Company is the designer and manufacturer of the rolling stock and other hardware and performs the systems engineering function. Sumitomo Denki, an electronics company, provides the control and communications equipment. Tokyo Denki provides the power equipment. The team also has an agreement with LTV Corporation of Dallas, Texas, for use of the Airtrans switching concept.

It should be noted that these systems are being developed by the transit industry. The only overt sign of interest in transit by the Japanese automobile industry is the CVS personal rapid transit system development, previously mentioned, in which the passenger vehicles are furnished by Mazda. There is a feeling among some circles in the transit industry, however, that the automobile industry "with its almost unlimited funds" is quietly at work on medium-capacity transit equipment development and they are, with some apprehension, awaiting specific announcements.

The Japanese systems discussed below are all pictured on Figure III -6. Summary data on the characteristics of these systems are presented in Table I-1.

Paratran

Paratran, "Public Automated Rapid Transit," is a system being developed by the Tokyu Car Corporation with headquarters and a test track in Yokohama, Japan. This company is a large manufacturer of all types of rolling stock. While most of its background is in large rolling stock for railroads and in large off-highway construction vehicles, the firm does have experience in transit type vehicles.

The company designed and built a monorail system for Osaka Expo '70. The vehicle in this system is rubber-tired, with a capacity of 30 seated and 105 standing passengers, a length of 52 feet, an empty weight of 53,650 pounds, and a maximum speed of 36 mph. Over a 6-month period, the system handled 35 million passengers with no failures of any kind.

The Paratran vehicle is a microbus size car with 24 seats and 16 standees for a design payload of 40 passengers. Under crush-loading conditions, 60 passengers can be accommodated. Nominal train consist is eight vehicles with a corresponding capacity of about 15,000 passengers per hour. Trucks are of the single-axle type with dual wheels. Pneumatic tires have been specially designed and manufactured for the Paratran vehicle by the Bridgestone Tire Company of Japan.

Power is supplied by a 400 volt A/C Ward Leonard system.¹ Dynamic regenerative braking is provided for the higher speeds and friction brakes for low speeds and holding.

VONA

VONA, "Vehicle of New Age," is a system being developed by Japan Rolling Stock Manufacturing Company (Nippon Sharyo Seizo Kaisha, Ltd.) with headquarters in Nagoya, Japan, and a fully automated, 1,300-foot test track in Toyokawa. Nippon Sharyo manufactures the rolling stock and is systems integrator for the VONA system for which Mitsui is the Program Manager. A smaller prototype system has been operating for 2 years in a kiddyland.

VONA is a center guide-rail type system. Minimum turn radius is 20 meters (65 feet). Nippon feels that center guidance provides better ride quality, particularly at higher speeds. Maximum speed for the VONA system is 60 km/hr (36 mph).

The test track includes some sections of guideway fabricated of steel and some of concrete. The steel surface is covered with epoxy grout to maintain traction when wet. Nippon Sharyo prefers the steel guideway for ease of fabrication and erection, and control of accuracy.

The VONA system is fully automated. It is currently configured to run on a 90-second headway. In addition to the usual block system minimum headway control, each vehicle has an acoustic (above hearing frequency) distance measuring device which measures the spacing between that vehicle and the preceding vehicle and maintains a prescribed minimum safe headway.

¹ This is a generic system which employs a generator driven by a constant speed motor. The armature of the generator is directly connected to that of the motor. Generator output voltage is controlled by varying its field excitation. These systems have largely been made obsolete by the advent of solid state power electronics.

Newtran

Newtran (NTS) is a system being developed by Niigata Engineering Company of Tokyo, Japan, in conjunction with a team of firms.

The Newtran vehicles are currently being operated on a 300-meter (1,000-foot) test track in Niigata City at low speed. Speed capability of the vehicle is 50 km/hr (30 mph), limited by its foam-filled tires. Niigata is working with Yokohama Rubber Tire Company to improve the ride quality of those foam-filled tires and to increase their speed capability. They feel the tires have a potential top speed of 80 km/hr (48 mph).

Niigata has a license to use the Airtrans on-board switching concept, but the vehicle is entirely different from Airtrans in all other respects. The firm stated that the ride quality was considerably better than Airtrans but did not wish to release the data yet, because the suspension system is still under development.

Currently, the guideway running and guidance surfaces are of steel for better experimental control. In a practical installation, however, Newtran is likely to suffer the same undesirable lateral accelerations as Airtrans, since its outboard guide wheels are located near the top of the sidewall where accuracy is difficult to maintain. Noise level at 30 m (100 feet) from the sidewall is 73 to 75 dbA. With a concrete sidewall, Niigata predicts a noise level of about 10 db lower.

Power is supplied at 3 Ø AC at the power pickup rail. Power control is by phase shift by means of a thyristor.

Braking is accomplished by a regenerative system at high speeds and air brakes for low speed and parking. A mechanical emergency brake is automatically applied in the event of power failure.

KCV Systems

The KCV systems are manufactured by Kawasaki Heavy Industries of Tokyo, Japan. This is the firm that manufactured the rolling stock for the Sapporo Rapid Transit system.

Kawasaki has standardized on three vehicle sizes. These are as follows:

	<u>Length</u>	<u>Seats</u>	<u>Standees</u>	<u>Total Passengers</u>
Sapporo ¹	44 ft	38	52	90
KCV-12	30 ft	24	26	50
KCV-13	21 ft	16	14	30

The firm sees no serious problems in developing a KCV-12 type vehicle in a 40-foot, 72-passenger size.

Kawasaki has paid a great deal of attention to ride quality. The company has found it necessary to provide a damping system between the guide wheels and the steering mechanism. It claims to be achieving better than the JNR No. 2 ride quality criteria curve, but feel it would be difficult to meet the No. 1 curve.

Noise has also received considerable attention. However, Kawasaki did not wish to make its noise level values public at this time, for competitive reasons.

The KCV system is completely automated, but if an operator is to be on board, the control system can be considerably simplified. The current test track experience has demonstrated a consistent stopping accuracy of ± 20 cm (± 0.8 inch), but the firm agrees such accuracy is not required. Braking is regenerative for economy in power usage. Pneumatic brakes are provided for low speed and stopped conditions.

Estimated total system cost for an elevated system of the KCV-12 type is 1 billion yen per km, or about \$6 million per mile. Subway is estimated to cost about 10 times more.

Kawasaki's testing program has been delayed by the energy crunch. The company felt its current test track at Kobe was too short to warrant a visit. However, their new large test track at Kakogawa in Hyogo will be operational about August 11, 1974, and Kawasaki would welcome our visit to the new facility.

MAT System

The MAT system, "Mitsubishi Automatic Transportation," is being developed by Mitsubishi Heavy Industries, Ltd., and Mitsubishi Denki (Electric) Corporation.

¹ One car of a two-car articulated unit.

The MAT test track near Hiroshima was not visited because of its distant location, so a personal assessment of its ride quality is not possible. However, discussions indicate that Mitsubishi has placed a great deal of emphasis on ride quality.

Power supplied at the rail is 550 volt, 3-phase ac. On board, the power is converted to dc through a thyristor rectifier to dc motors. Power input to the rectifiers is controlled by means of phase shifting, and is continuously variable.

Production MAT vehicles will incorporate dynamic, regenerative braking. The braking system will generate ac power which will be delivered back to the power station. The regenerative braking will be used to reduce speed to 12 mph, at which point a friction braking system will take over the braking function. Braking rates are controlled by a computer to the following levels:

Standard	4 km/hr/sec (2.4 mph/sec)
----------	---------------------------

Emergency	6 km/hr/sec (3.6 mph/sec)
-----------	---------------------------

Operational management of the system is by a hierarchy type control with both central and local elements. Nominal headway is 90 seconds with dwell times of 20 to 30 seconds.

Current testing is with single cars and two-car trains. Train consist can go as high as 20 cars.

Mitsubishi is not working on a large vehicle of the Honolulu size; however, the company would like to whenever the requirement is better defined.

SUMMARY OF DESCRIPTIONS

The large train systems carry up to 50,000 passengers/hour in the peak direction (in Mexico and Sapporo, with passenger crowding that would probably be unacceptable to Americans). Intermediate-sized vehicles are designed to carry up to 22,000 passengers/hour, but no system has yet been installed carrying even 10,000/hour. The three operational, large systems all run at approximately 45 mph top speed. Several other systems have been conceived with top speeds of 60 mph or more, but this performance has not yet been demonstrated, and engineers of the systems admit that much work remains to be done before high speeds are attainable. The large systems are usually supported on double-axle bogies, although Sapporo has single-axle drive bogies which are being replaced by double-axle bogies on newer trains. Most small and intermediate systems now use single axles, although Ford, Westinghouse, and Bendix are all engaged in engineering evaluation of single vs. double axle for vehicles in the 40-foot long range.

GUIDANCE AND STEERING

CATEGORIES

The systems reviewed in this technology survey incorporate a variety of concepts for the guidance and steering of the vehicles. These concepts can be conveniently organized into four generic categories with corresponding symbols as follows:

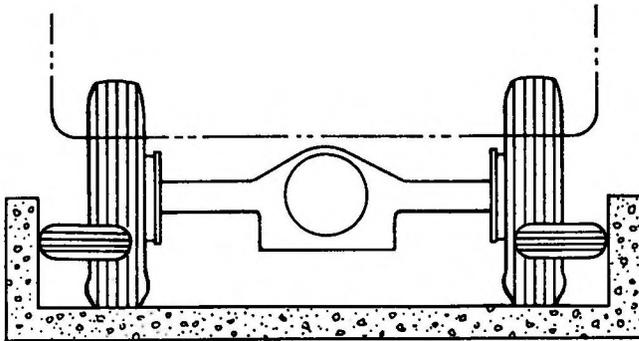
- o OSA, Outboard Steered Axle: This system (Figure III -7a) is normally used with a guideway of U-shaped channel cross sections. Horizontally oriented guide wheels bear on the vertical legs of the channel. These bearing or guidance surfaces are located outboard of the main support wheels. The guide wheels, which may be located high or low on the guidance surface, are connected to the axle, sometimes through an input conditioning mechanism, to control the rotation of the axle assembly and provide steering.
- o OSW, Outboard Steered Wheel: This concept (Figure III -7a) essentially is the same as the OSA concept except that steering is provided by positioning of the wheel rather than the axle.
- o CGB, Center Guide Beam: This concept (Figure III -7b) employs an I-beam at the guideway centerline to provide lateral guidance. The top of the I-beam may be above, below, or flush with the plane of the main support wheel running surface. The flush position is employed more often since this position simplifies the switching problem. Horizontally oriented guide wheels, usually one pair fore and one pair aft of the main support wheels, engage the web of the I-beam on both sides. In some systems, only the forward pair contact the I-beam in order to minimize main tire scuffing during turns.
- o IBG, Inboard Guidance: This concept (Figure III-7c) is similar in most respects to the OSA system except that the vertically oriented guidance surfaces have been moved inboard of the main support wheels and placed below the plane of the main support wheel running surface.

The surveyed systems fit into these guidance categories as follows:

OSA: Bendix Animal Domain Ride
Ford Fairlane, etc.
Montreal Metro
Mexico City Metro
Kawasaki KCV

FIGURE III-7

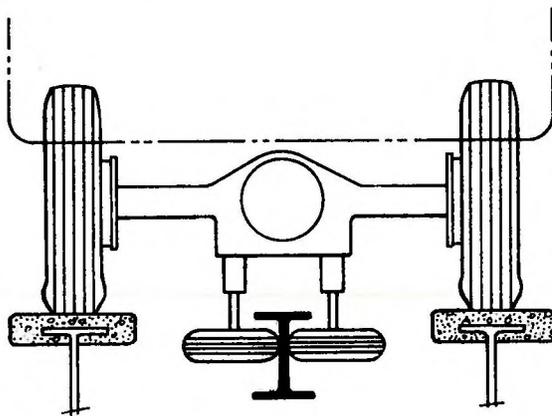
GUIDANCE CONCEPT CATEGORIES



(a) OSA, Outboard Steered Axle
OSW, Outboard Steered Wheel

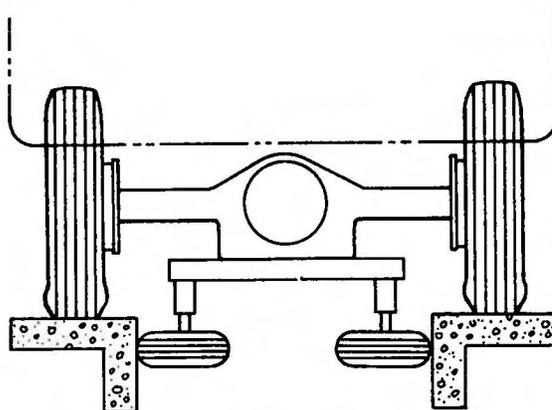
OSA: Bendix Animal Domain Ride
Ford Fairlane, etc.
Montreal Metro
Mexico City Metro
Kawasaki KCV

OSW: LTV Airtrans
Boeing Morgantown
Niigata Newtran



(b) CGB, Center Guide Beam

CGB: Rohr San Pasqual, etc.
Westinghouse Skybus, etc.
Nippon Sharyo VONA
Mitsubishi MAT
Sapporo Rapid Transit System



(c) IBG, Inboard Guidance

IBG: Tokyu PARATRAN

OSW: LTV Airtrans
Boeing Morgantown
Niigata Newtran

CGB: Rohr San Pasqual, etc.
Westinghouse Skybus, etc.
Nippon Sharyo VONA
Mitsubishi MAT
Sapporo Rapid Transit System

IBG: Tokyu Paratran

The guidance concepts for these systems are described below.

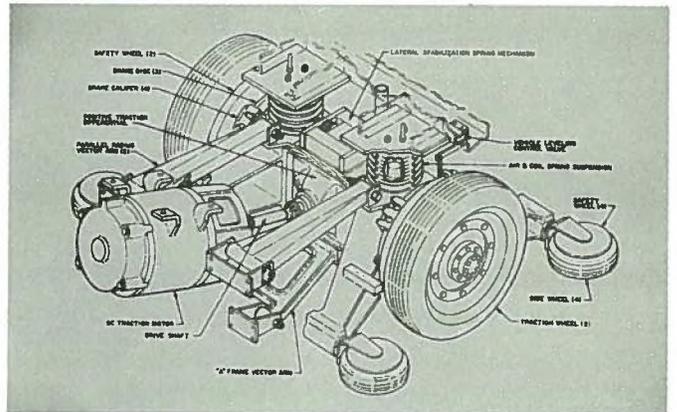
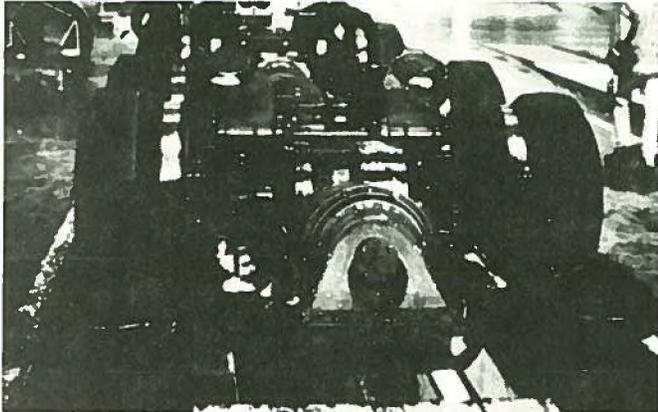
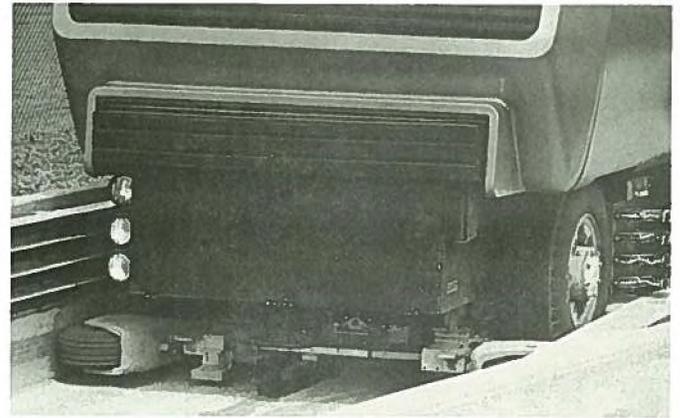
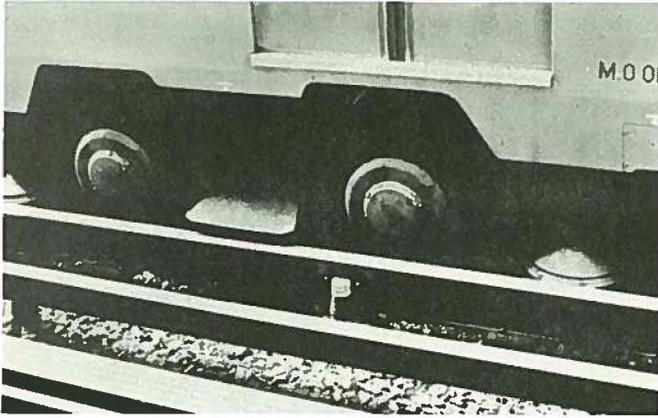
OUTBOARD STEERED AXLE

The Montreal and Mexico City Metro systems utilize the OSA (Outboard Steered Axle) guidance concept as shown on Figure III-8. Trucks are of the dual-axle, single-tire type. During normal operation, guidance is provided by horizontally oriented guide wheels bearing against vertical guide beams located on both sides of the guideway. The entire truck (bogey) is free to rotate about a central pivot point to accommodate curves in the guideway. The guide wheels, fore and aft on the truck, are pre-loaded so they are always in contact with the guide beams, thus providing positive lateral location.

Horizontal guidance and steering through switches are provided by a different concept. Flanged, steel, railroad type wheels of slightly smaller diameter than the support tires are mounted on the axle immediately in-board of each tire. During switch pass-through operation, lowered elevation of the rubber tire running surface causes these flanged wheels to contact the rails of a conventional type railroad switch, and guidance and steering are provided in the normal steel-wheel, steel-rail manner. These steel wheels also provide an emergency support function as described later in the section on support.

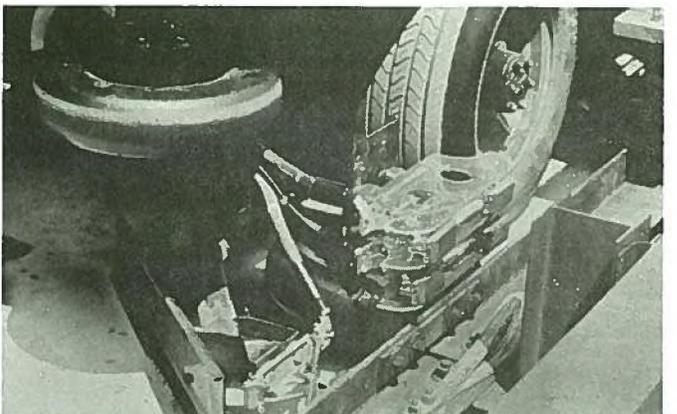
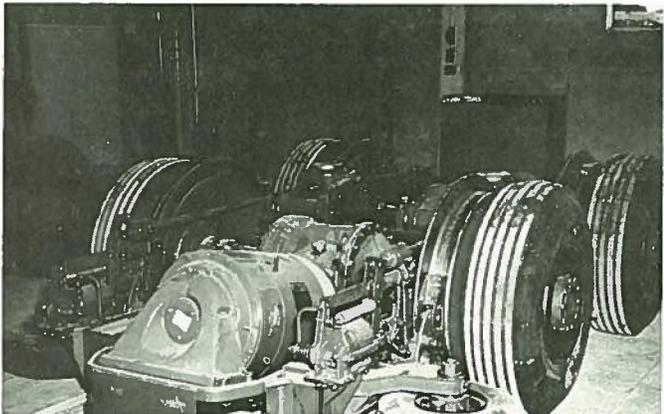
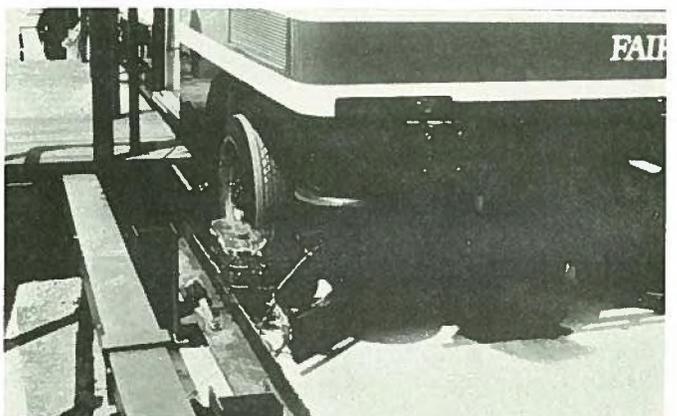
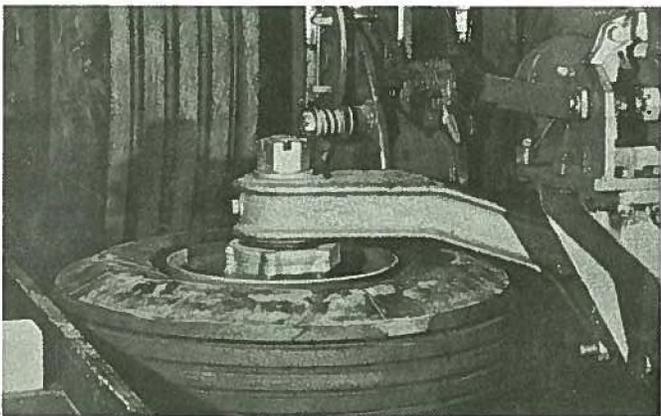
The Bendix Dashaveyor and Ford ACT systems (Figure III-8) also employ the OSA guidance concept. In these instances, however, the reaction of the guide wheel controls the angular orientation of a single-axle, single-tire bogey. This is true also of the Kawasaki KCV system, a similarity that stems from technical agreements between Kawasaki and Bendix on guidance concepts.

OUTBOARD GUIDANCE/STEERED AXLE



METRO, MEXICO CITY, MEXICO

TRANPO 72, BENDIX DASHAVEYOR



METRO, MONTREAL, CANADA

FAIRLANE, FORD MOTOR COMPANY

FIGURE III-8

In the Ford ACT system, the guide wheels are preloaded against the lower portion of the guide rail by a tapered leaf spring to condition the guidance inputs to the steering system. In the Bendix system, guide wheels are mounted rigidly to an aluminum bracket which provides for very limited compressive lateral movement. The Ford ACT system appears to provide better lateral ride quality characteristics due, at least in part, to the guidance signal conditioning provision.

OUTBOARD STEERED WHEEL

Guidance systems of the OSW type are illustrated on Figure III-9.

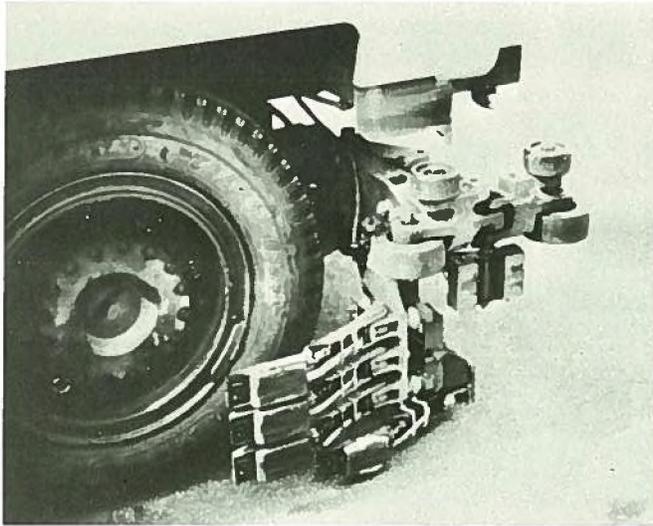
The LTV Airtrans system (and LTV's Japanese guidance and steering licensee, Niigata Newtran) also has lateral guide wheels that bear against vertical guide surfaces; in this case, the channel sidewalls. However, the guide wheels are fixed to the steering linkage, and the steering linkage steers the wheels similarly to the steering in an automobile. Initially, the linkage between the guide wheels and the steering mechanism provided a direct mechanical connection, but track tests indicated that some dampening was required to reduce the effects of minor irregularities in the guideway on lateral ride quality.

The Boeing Morgantown PRT also is a steered-wheel system, but it differs from the other outboard systems because only one guide wheel at a time bears against a side guide wall. Depending on its destination and location in the system, the vehicle is directed to guide itself against one sidewall or the other. The vehicle maintains its lateral position in the guideway through a biased position of the support wheels; the wheels are always turned slightly toward the sidewall on which the sensor wheel is bearing. (The Boeing system is unidirectional, and has sensor wheels on the front end only.) However, Boeing is currently developing a design for bi-directional vehicles as well as a system in which the support wheels are not always turned.

CENTER GUIDE BEAM GUIDANCE

Guidance systems utilizing the center guide beam (CGB) concept are shown on Figure III-10. The Westinghouse system in the United States and several of the Japanese systems (Sapporo, VONA, and MAT) feature an I-shaped, centrally located guide beam. The upper flange of this beam is at the same elevation as the guideway running surfaces for ease of switching. Each bogey is fitted with two pairs of guide wheels - one pair forward and one pair aft of the support axles. An exception is the two-axle trucks on the Sapporo system which are rigidly fixed to the vehicle frame.

OUTBOARD GUIDANCE/STEERED WHEEL



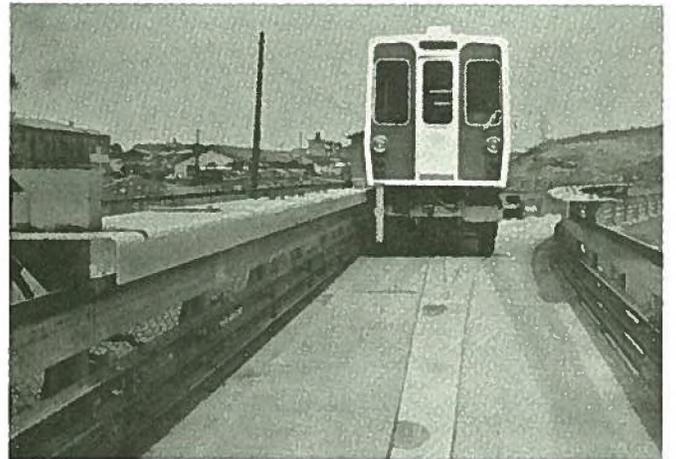
A. AIRTRANS, GUIDE WHEEL CONFIGURATION



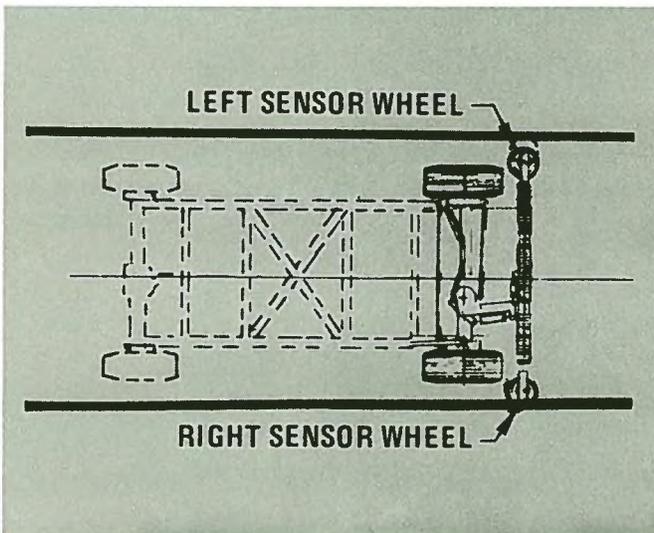
D. NEWTRAN, GUIDE WHEEL ASSEMBLY



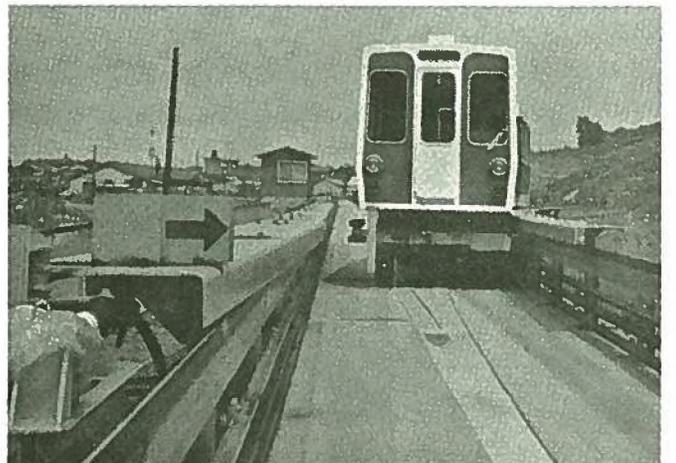
B. MORGANTOWN, GUIDE WHEEL CONFIGURATION



E. NEWTRAN, TANGENT POSITION



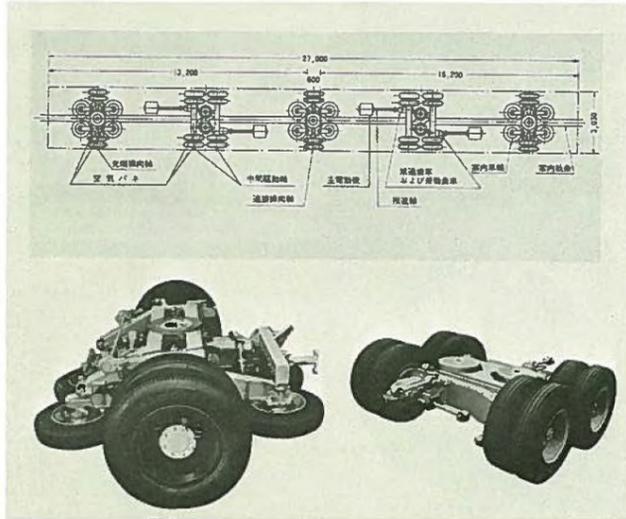
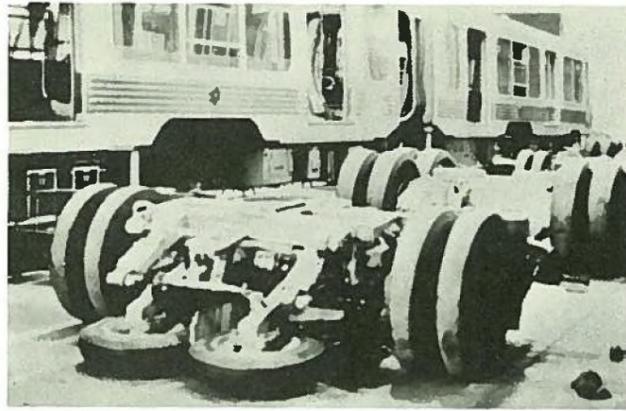
C. MORGANTOWN, GUIDANCE SCHEMATIC



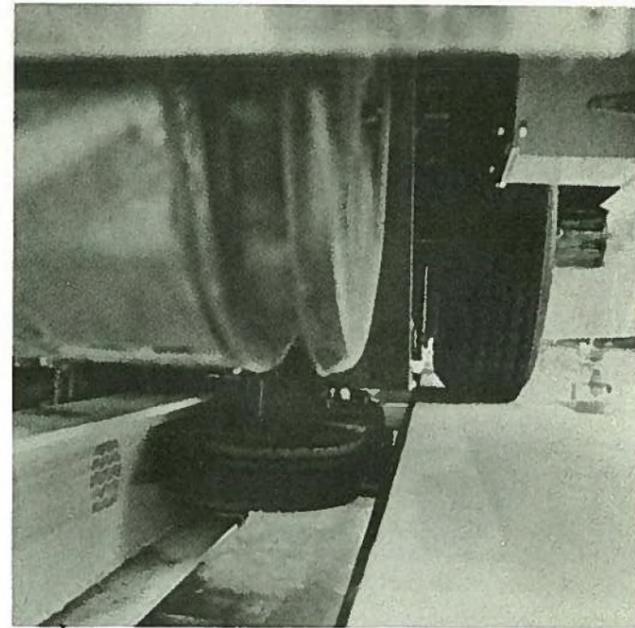
F. NEWTRAN, TURNOUT POSITION

FIGURE III-9

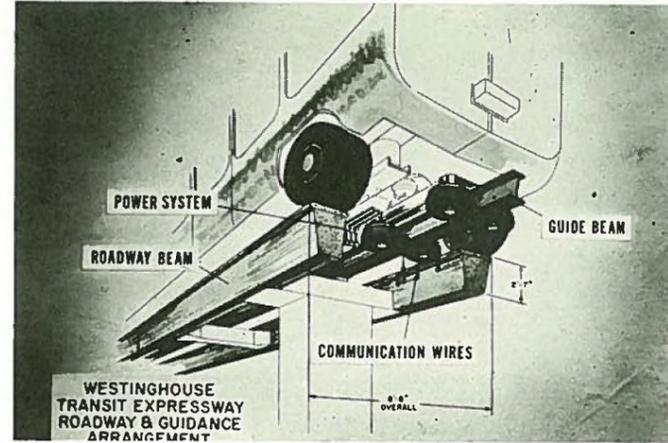
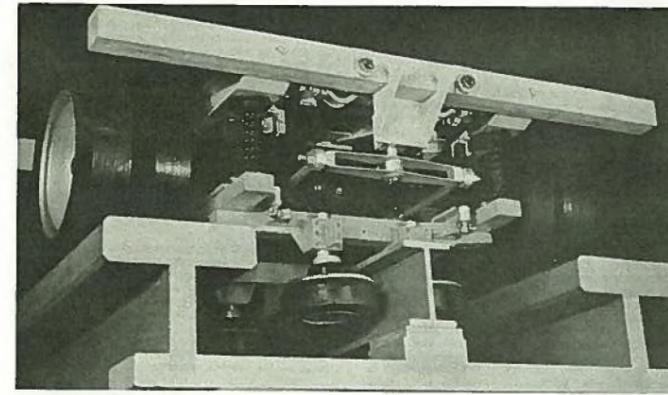
CENTER GUIDEBEAM GUIDANCE



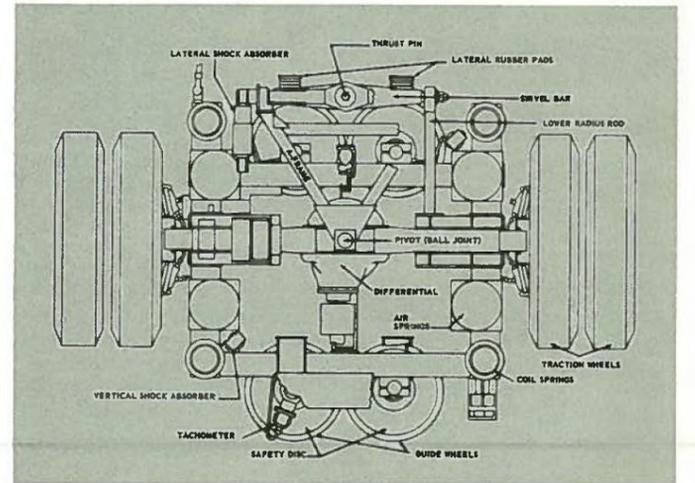
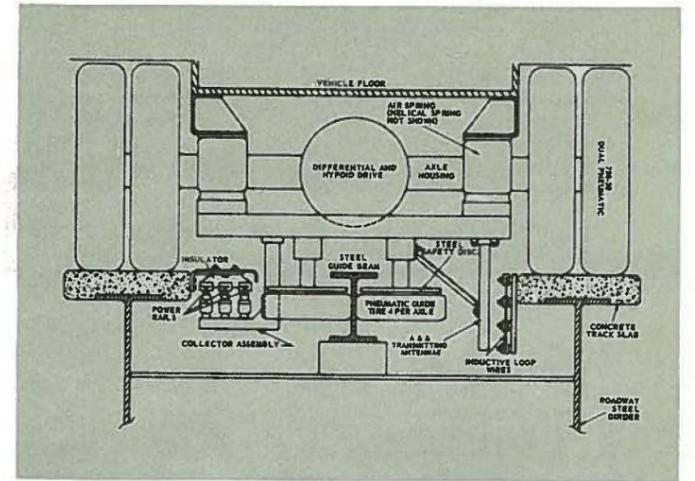
SAPPORO, RAPID TRANSIT SYSTEM



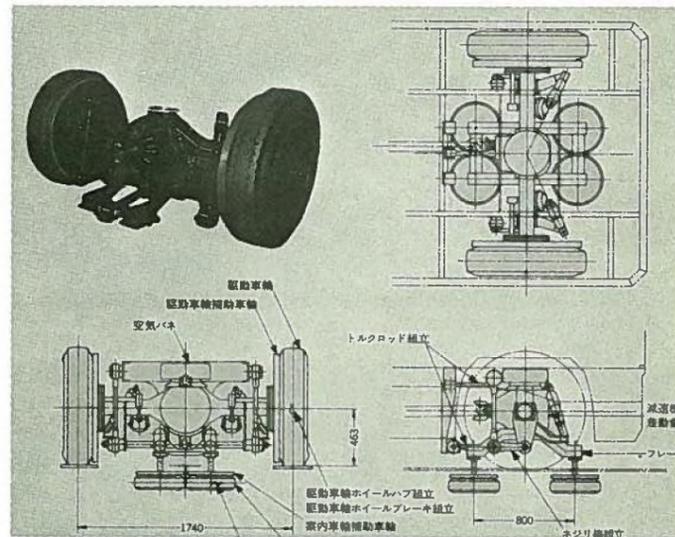
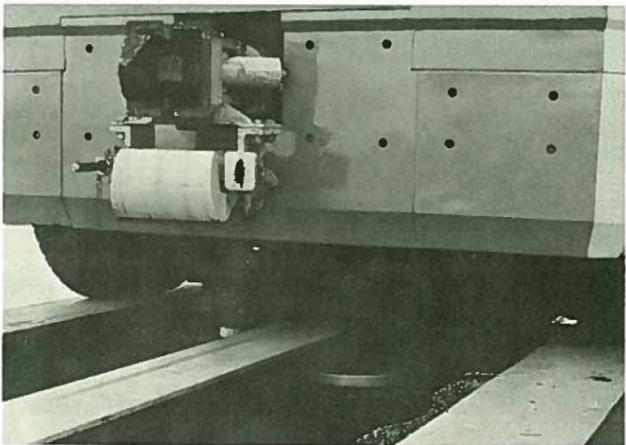
VONA, JAPAN ROLLING STOCK MANUFACTURING COMPANY



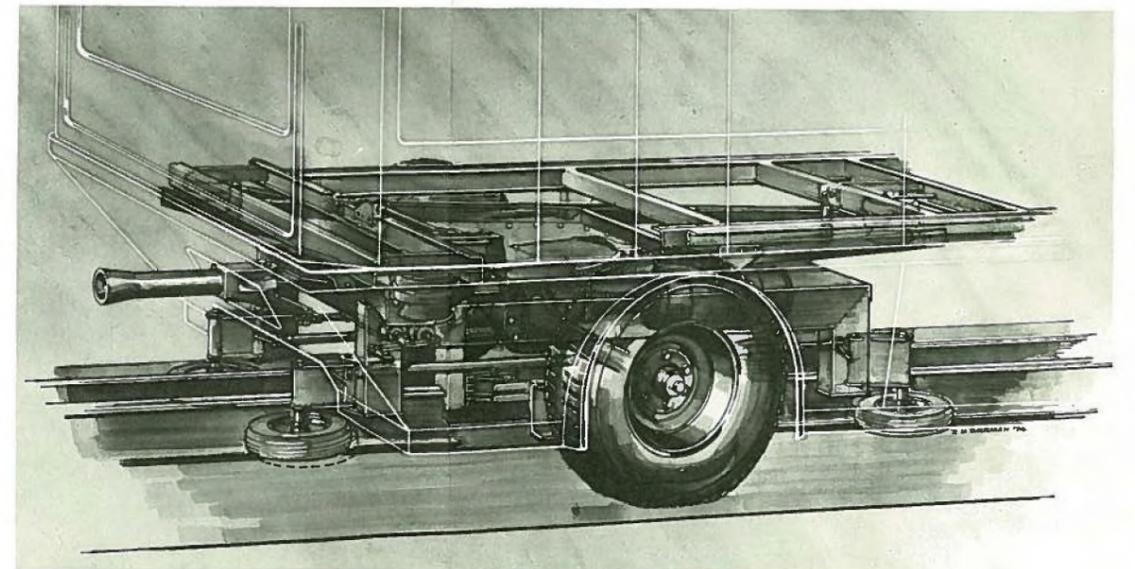
TRANSIT EXPRESSWAY, WESTINGHOUSE



MAT, MITSUBISHI CORPORATION



RAIL BUS, ROHR CORPORATION



CENTER GUIDEBEAM GUIDANCE
FIGURE III-10

The guide wheels engage the center guide beam, providing guidance and steering. For the Sapporo vehicles, which were built by Kawasaki, only the lead pair of guide wheels engage the guide beam. The guide wheel mount beams are pivoted about a central point so when the direction of travel of a vehicle is reversed, the newly positioned front guide wheels grasp the guide beam and the rear set release it. This feature has been incorporated to minimize tire scuffing as the steerable bogies negotiate curves.

The Rohr systems represent a modified center guide beam concept. The centrally located beam is made of two channel sections with space provided between the vertical webs. The resulting slot is used for power and signal rails. The major difference, however, is the location of the center guide beam completely above the elevation of the guideway running surfaces. This arrangement imposes substantially different switch configuration requirements on the system.

INBOARD GUIDANCE

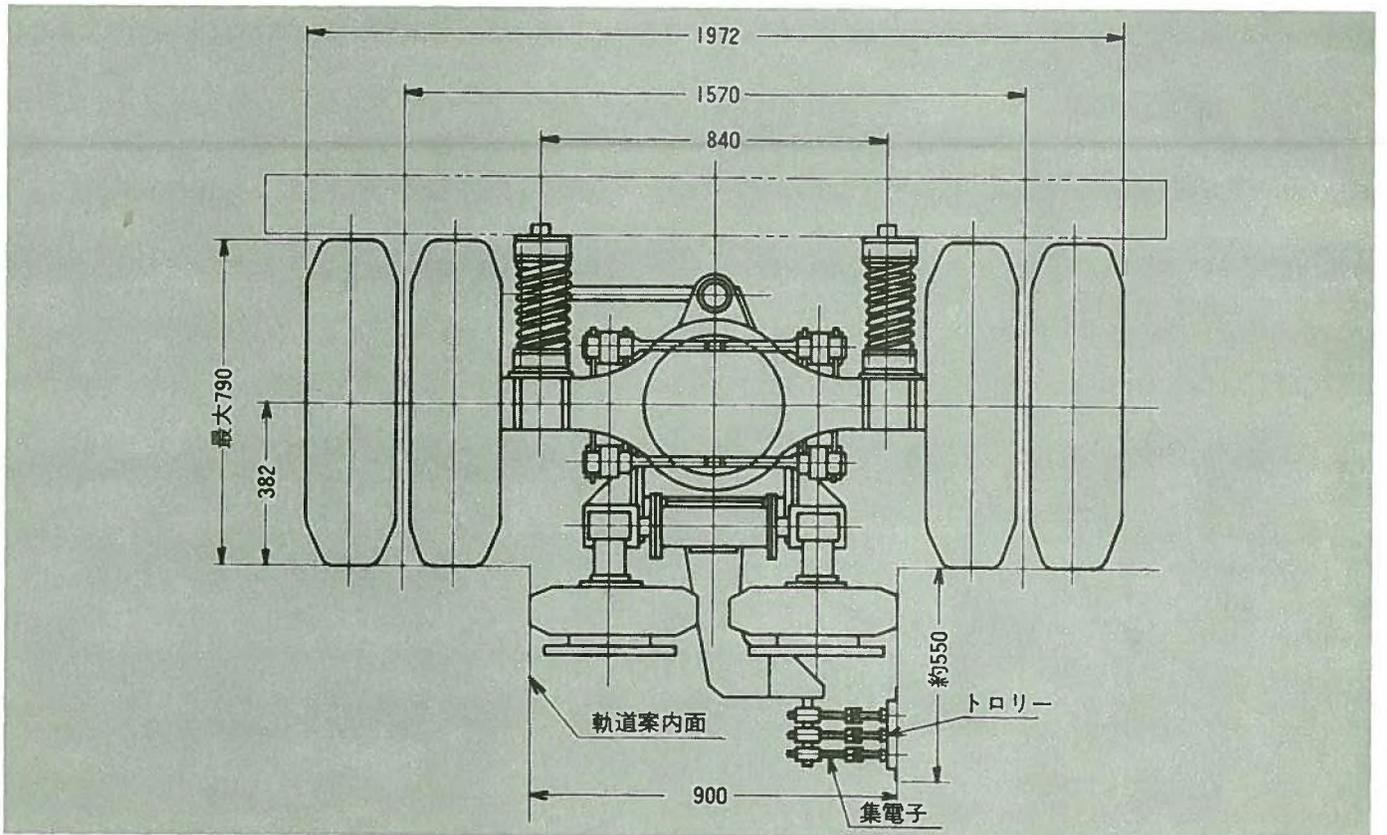
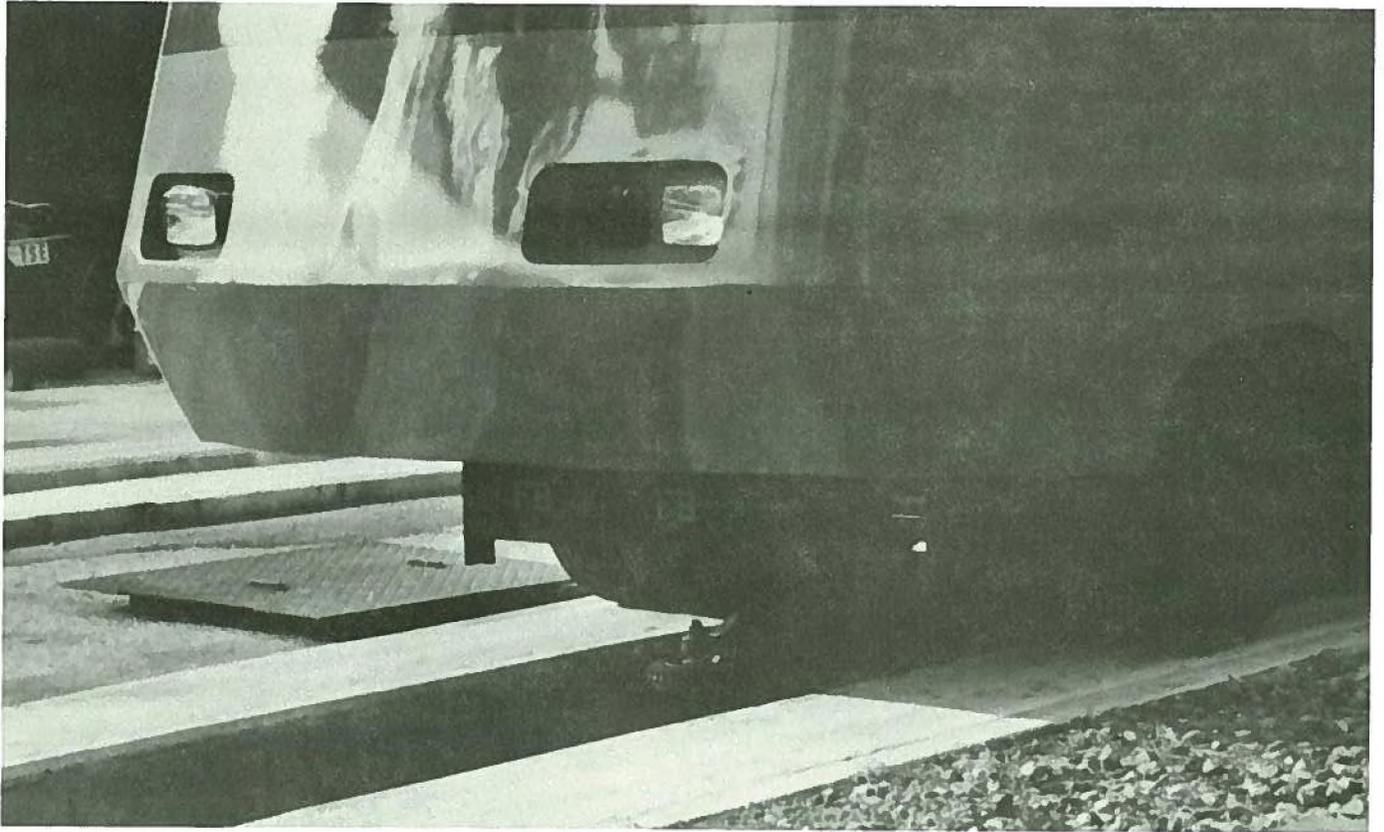
Only one of the systems surveyed incorporates the IBG guidance concept. This is the Tokyu Car Corporation Paratran system. Guidance features for this concept are shown on Figure III-11. The horizontal guide wheels are located in a central slot below and inboard of the guideway running surfaces. Because of the high steering forces with the dual-tire arrangement, a power steering system has been incorporated. As will be described later, Tokyu has worked out a unique solution to what was a potentially difficult switching problem.

SUPPORT

GENERAL

Several different types of suspensions and several kinds of tires are used on the various systems. The Metro systems have large trucks somewhat similar to conventional railroad trucks, with four rubber-tire (steel-belted Michelin radials) and four steel wheels immediately inboard of the tires. (See Figure III-8.) The steel wheels serve as the support wheels for switching, as emergency back-up if a tire fails, and as brake drums against which wooden brake shoes press. On powered vehicles, the truck contains the motors and all running gear. The trucks are fastened to the vehicle chassis through a central post, freeing them for limited lateral rotation.

INBOARD GUIDANCE



PARATRAN, TOKYU CAR CORPORATION

FIGURE III-11

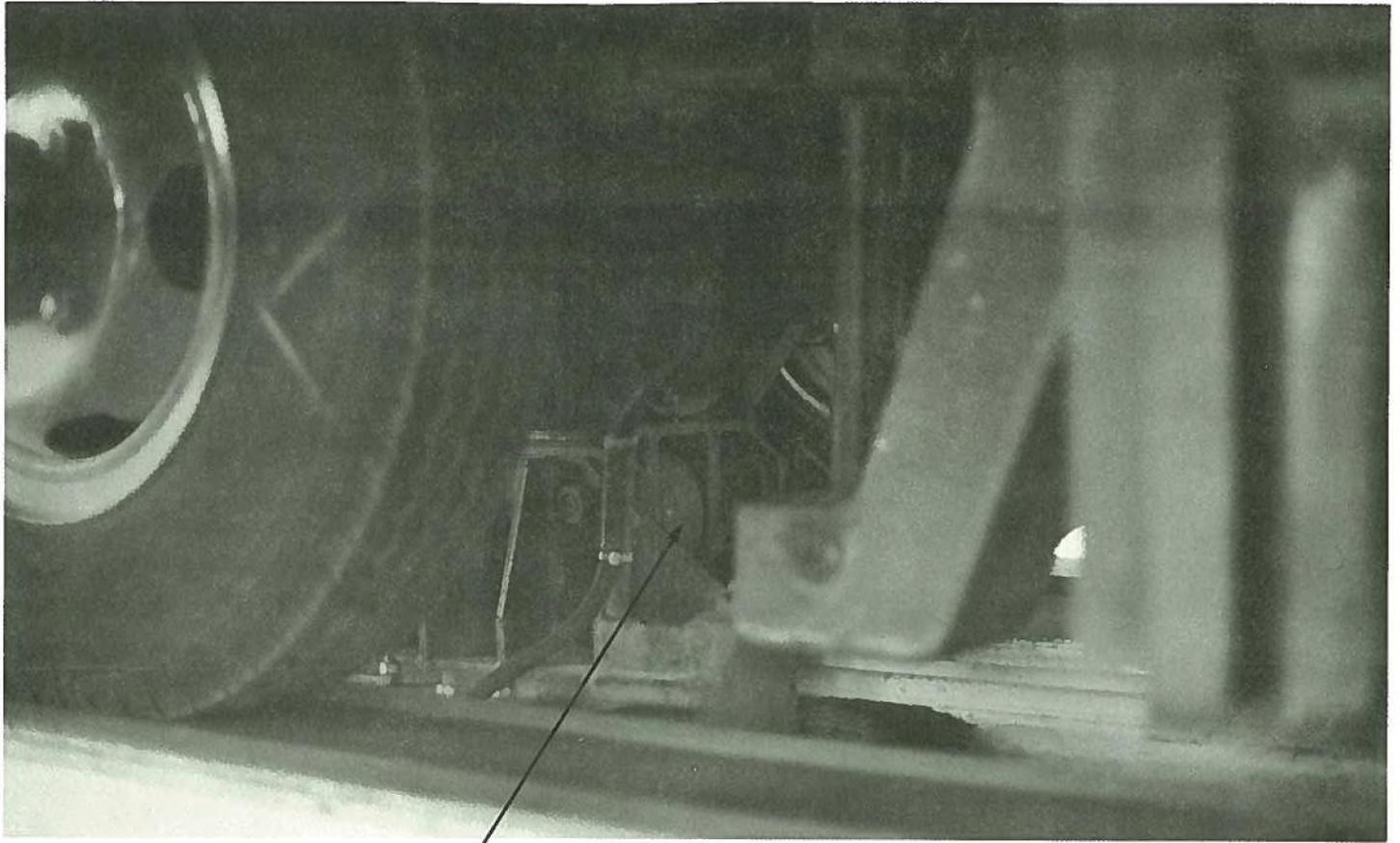
The Sapporo Metro presently has single-axle unpowered guidance trucks, with dual-axle fixed power trucks (Figure III-10). However, on new trains for Sapporo, all trucks will be dual-axle. Each axle has four pneumatic tires so that in case of a blowout, emergency support is provided by the unblown tire.

The Rohr Monorail systems (as currently used) also have double-axle trucks; on the larger systems, each truck has eight support tires (Figure III-10). Rohr uses conventional heavy-duty truck tires, pneumatically filled. The trucks include all propulsion, braking, steering, and suspension; on the smaller Rohr systems, one truck is located between each pair of cars, while the larger systems have two units on each car. The trucks are mounted via a slewing ring to accommodate horizontal curves; vertical air springs with shock absorbers form a secondary suspension, isolating the car body from the truck (the tires themselves are the primary suspension). The wheels are driven by chains. Dual tires provide emergency support.

Westinghouse (Figure III-10), Ford, and Bendix (Figure III-8) all have automotive type single axles, attached to the vehicle through combinations of coil and air springs. Wheels are driven through an automotive type differential. The LTV and Boeing systems are similar, but the wheels themselves steer rather than swing with the whole axle. In addition to steel-belted radial and pneumatic truck tires, some of the systems use foam-filled truck tires or dual chamber safety tires. Most manufacturers and operators are continually experimenting with new tire designs; no one appeared satisfied with the tires currently available (even the Metro operators are awaiting availability of nonsteel-belted radials from Michelin, to improve ride quality and reduce the electrical shorting problems now experienced after tire blowouts).

The Japanese systems, for the most part, have single-axle bogies, and only the Newtran system has steerable wheels (the others rotate the whole axle). The Japanese systems also use combinations of coil and air springs, and they too are experimenting with both pneumatic and foam-filled tires. The MAT system has flangeless steel wheels (Figure III-10) immediately inboard and of slightly smaller diameter than the support tires. Should a tire failure occur, these wheels contact the guideway running surfaces, providing low speed emergency support. The VONA system bogies have small diameter, steel flangeless wheels (Figure III-12) mounted at the center. In the event of a tire failure, one of these wheels contacts the upper flange of the center guide beam, providing emergency support.

FIGURE III-12 VONA CENTRALLY-LOCATED EMERGENCY SUPPORT WHEEL



EMERGENCY SUPPORT WHEEL

TIRE LOADS

Table III-2 is a summary table of the 19 systems investigated during the survey. The "load-per-tire" shown here is based on the design payload. In determining static applied loads, these values should be increased by about 20 percent to account for crush loading.

The data from Table III-2 have been plotted on Figure III-13. The steepest curve on Figure III-13 is for vehicles with single-axle, single-tire trucks, i.e., with four tires per vehicle. Systems 1, 3, 4, 5, 6, 12, 13, 14, and 15 are of this type covering a design gross weight range of almost 30,000 pounds. The intermediate curve is for vehicles with either single-axle, dual-tire trucks or dual-axle, single-tire trucks, i.e., eight tires per vehicle. The gross weights for the medium-capacity systems go up to 50,000 pounds. The lowest curve is for vehicles with dual-axle, dual-tire trucks, i.e., vehicles with 16 tires each.

The switchover from four tires per vehicle to eight tires per vehicle with current state-of-the-art appears to occur at a gross weight of about 30,000 pounds. System No. 15 used dual wheels for reasons of mobility in case of a tire failure. This approach has led to very conservative tire loadings. The "failed-tire" problem has been handled in other ways by the other systems.

Eight-tire vehicles in operation have tire loads extending up to 10,000 pounds per tire (Mexico City and Montreal). These systems have very good tire life (up to 180,000 miles) but do suffer occasional blowouts.

The point (see Figure III-13) for system No. 14 is for the Sapporo hybrid configuration. This is a system of seven axles with dual wheels for an articulated pair of vehicles giving 28 tires per pair, or 14 tires per vehicle. This point lies close to the 16-tire-per-vehicle curve as it should. The Sapporo vehicles are being redesigned to eliminate the single-axle (unpowered) trucks, since these have resulted in a vibration problem. The new vehicles will have dual-axle, single-wheel trucks (eight tires per vehicle) as shown by point number 14a on the graph. This will give a less conservative tire loading.

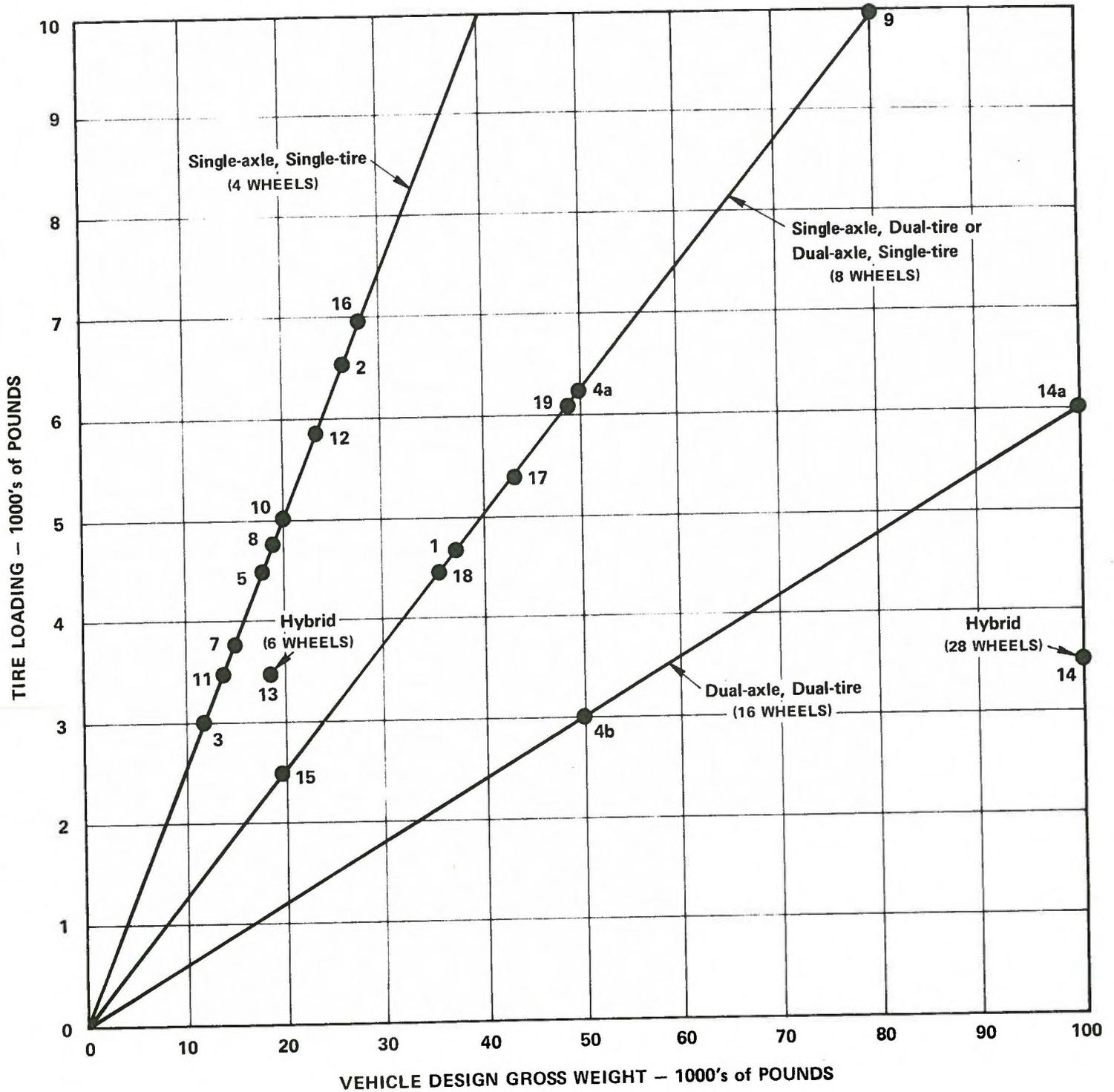
It appears, then, that for medium-capacity systems with speed capability up to 35 or 40 mph, current tire technology limits four tire systems to about 30,000 pounds design gross weight and eight tire systems to about 50,000 pounds gross weight.

**TABLE III-2
TIRE LOADINGS**

SYSTEM OR MANUFACTURER		MODEL	DESIGN GROSS WEIGHT	TIRES PER VEHICLE	LOAD PER TIRE
			Lbs.	No.	Lbs.
1	Bendix-Dashaveyor	Family 2	37,500	8	4,687.5
2	Bendix-Dashaveyor	Animal Domain Ride	26,000	4	6,500
3	Boeing	Morgantown	11,900	4	2,975
4	Ford Act	El Paso/Juarez	50,000	8-16	6,250-3,125
5	Ford Act	Fairlane	18,900	4	4,725
6	Kawasaki	KCV-12	26,222	-	-
7	Kawasaki	KCV-13	14,412	4	3,603
8	LTV	Airtrans	20,000	4	5,000
9	Mexico City	Metro	80,229	8	10,029
10	Mitsubishi	MAT	19,216	4	4,804
11	Japan Rolling Stock Manufacturing Co.	VONA	13,380	4	3,345
12	Niigata Engineering Co.	Newtran	23,180	4	5,795
13	Rohr Corporation	DMV	32,000	6	5,333.3
14	Sapporo	Metro	100,924	28	3,604.5
15	Tokyu Car Corporation	Paratran	19,440	8	2,430
16	Westinghouse	Transit Expressway	27,600	4	6,900
17	Westinghouse	Satellite Transit System	42,800	8	5,350
18	Westinghouse	Tampa Shuttle System	36,500	8	4,562.5
19	Westinghouse	Satellite Transit Shuttle	49,200	8	6,150

FIGURE III-13

TIRE LOADING vs. DESIGN GROSS WEIGHT



Various Support Configurations

- | | |
|--|---|
| 1. Bendix-Dashaveyor, Family 2 | 11. Japan Rolling Stock Manufacturing Co. |
| 2. Bendix-Dashaveyor, Animal Domain Ride | 12. Niigata, Newtran |
| 3. Boeing, Morgantown | 13. Rohr, DMV |
| 4. Ford, El Paso/Juarez | 14. Sapporo, Metro |
| 5. Ford, Fairlane | 15. Tokyu, Paratran |
| 6. Kawasaki, KCV-12 | 16. Westinghouse, Transit Expressway |
| 7. Kawasaki, KCV-13 | 17. Westinghouse, Satellite Transit System (SeaTac) |
| 8. LTV, Airtrans | 18. Westinghouse, Tampa Shuttle System |
| 9. Mexico City, Metro | 19. Westinghouse, Satellite Transit Shuttle (Miami) |
| 10. Mitsubishi, MAT | |

TIRE LIFE

Only the three large rubber-tired transit systems and the Westinghouse airport systems have subjected tires to usage approaching their ultimate life. Speeds at the metro systems have been limited to 45 mph. At these speeds, experience of these systems indicates a tire life of 150,000 to 200,000 miles. As noted earlier, design gross weight tire loads are about 10,000 pounds for Mexico City and Montreal and 3,600 pounds for Sapporo.

An interesting point made at Sapporo is that when bus tires were used on the Metro guideway, their life was extended from the normal roadable life of 48,000 miles to a guideway life of 135,000 miles, or an increase of almost 300 percent. Sizeable increases in tire life for transit guideway operation are not surprising due to the superior condition of the running surface and the more uniform and controlled conditions of acceleration and braking.

Experience and predictions for the medium-capacity systems indicate tire life capabilities on the order of 50,000 to 100,000 miles (the Westinghouse Sea-Tac system, which is in continuous 24-hour operation, has experienced 40,000 to 60,000 miles tire life, but their total tire contract for nine vehicles amounts to only \$300 per month). An exception is the Boeing Morgantown system in which tire life is substantially shorter due to the scuffing imposed by the basic guidance and switching concept.

It should be noted that experience to date on the medium-capacity systems has been limited to operations at low speeds, - 30 mph or less. Also, several of the systems are using foam-filled tires which are currently limited to speeds of about 35 mph. In addition, these foam-filled tires are being found to have an adverse, and perhaps unacceptable, effect on ride quality. As a result, their use is under reconsideration on many systems where they are now incorporated.

GUIDEWAYS

GENERAL

Concepts and configuration for guideways (and switches) are strongly influenced by the type of guidance selected for the particular system. The types of guidance significant to the current survey were categorized as:

- o OSA - Outboard Steered Axle
- o OSW - Outboard Steered Wheel
- o CCB - Center Guide Beam
- o IBG - Inboard Guidance

These are described in the section, "Guidance and Steering." The concepts have also been presented pictorially on Figure III-7. The guideways being developed or in operation for these guidance categories are described below.

CENTER GUIDE BEAM

Details for the Center Guide Beam (CBG) category are shown on Figure III-14.

The Rohr guideway (Figure III-14) is the simplest of those surveyed - basically, a narrow concrete slab with the guide beams mounted over the center. In most installations, the guideway is elevated or at grade, but some tunnel installations also exist. Operations occurring over these guideways to date have been at low speed.

The Westinghouse guideway (Figure III-14) consists of two concrete slabs, mounted on both ends of steel cross girders in elevated configuration or concrete ties at grade. The steel I-beam guide beam is mounted between the track slabs. The guideways at Tampa and Seattle-Tacoma Airports are primarily concrete, elevated at Tampa and in subway at Sea-Tac.

The Sapporo Metro and many of the Japanese people-mover guideways are similar to the Westinghouse guideway, with a central guide beam located between two running slabs. Most of the Japanese guideways are constructed from steel; except for Sapporo, they are all test tracks. To avoid such an inclement weather problem as loss of traction during rainy and icy conditions, the entire exposed portion of the Sapporo guideway has been enclosed in a metal and glass cover. No adverse visual or disorientation problems were experienced while riding the system.

The VONA and MAT guideways, as embodied so far only in test tracks, are constructed of steel, although a portion of the VONA test track is made of concrete for test purposes. For their test tracks, these firms prefer steel for economy, ease of fabrication and erection, and accuracy. The running surfaces of these guideways (both steel and concrete) have been coated with a thin layer of epoxy grout to improve traction and wear characteristics.

INBOARD GUIDANCE

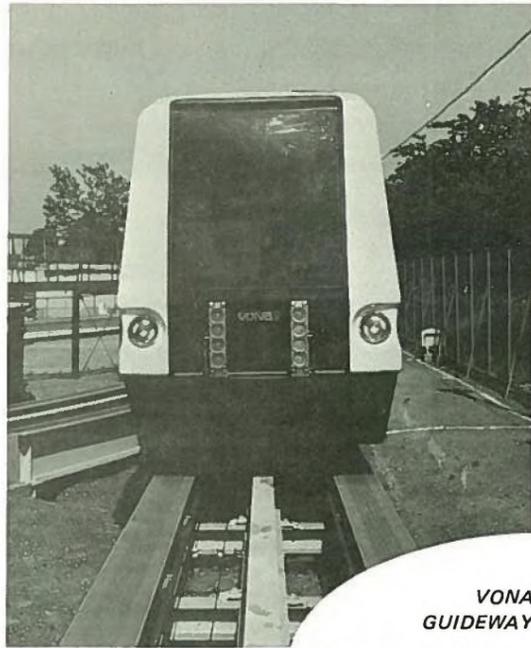
Representative of the Inboard Guidance concept is the Paratran system as shown on Figure III-14. In this concept, the guidance "slot" and running surfaces are formed by two prestressed concrete beams. These beams are held in the proper orientation by transverse concrete ties spaced at about 50-foot centers. The same guideway running surface and guidance configuration could also be obtained through use of fabricated steel sections.

OUTBOARD GUIDANCE

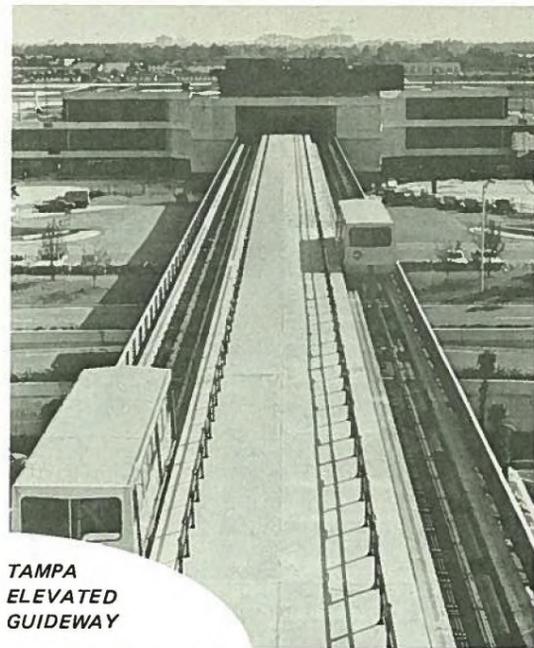
Guideway concepts for the medium-capacity systems utilizing the outboard guidance concepts are shown on Figure III-15. The Bendix, Ford, Boeing, and LTV guideways are all essentially concrete, or concrete and steel, channels. (See Figure III-15.) Construction may be by prestressed or poured slabs, but the sidewalls have usually been poured in place. Ford has also used aluminum guideways, but presently is conducting experiments at its Cherry Hill Test Track on several different types of concrete guideway. All four guideways can be built elevated, at grade, or in tunnel. Bendix and Ford install separate metal guide surfaces near the bottoms of the sidewalls, while Boeing and LTV use the concrete walls as the guide surface. LTV has indicated that it would probably install a separate guide surface in a future system, since it has not been able to construct concrete guide walls with sufficient alignment accuracy to avoid excessive lateral jerks. The problem of guideway accuracy requirements is more severe on the LTV system, since the guide wheels contact the guideway near the top of the sidewalls where accurate alignment is more difficult to maintain.

The large Metro systems have guideways with narrow gauge, conventional steel rails; slabs are set outside as a running surface for the rubber tires. (See Figure III-8.) In Montreal, the slabs are concrete throughout the system (except for a few steel slabs in the yards). In Mexico City, steel slabs are used throughout. The choice between steel and concrete was made partially because of economics; also, steel slabs are apparently less easily damaged and more easily replaced after seismic disturbances, common in Mexico. Guide rails in both cities were mounted on posts alongside the slabs. Tracks were laid either on ballast or on concrete. Montreal and Mexico guideways are either in subway or at-grade, but aerial installation is also feasible, albeit with a rather heavy and bulky structure.

GUIDEWAYS FOR CENTER GUIDEBEAM AND INBOARD GUIDANCE



VONA
GUIDEWAY

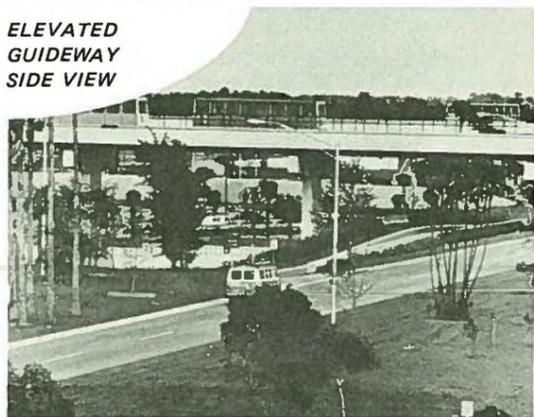


TAMPA
ELEVATED
GUIDEWAY

WESTINGHOUSE TRANSIT EXPRESSWAY



SOUTH
PARK
GUIDEWAY

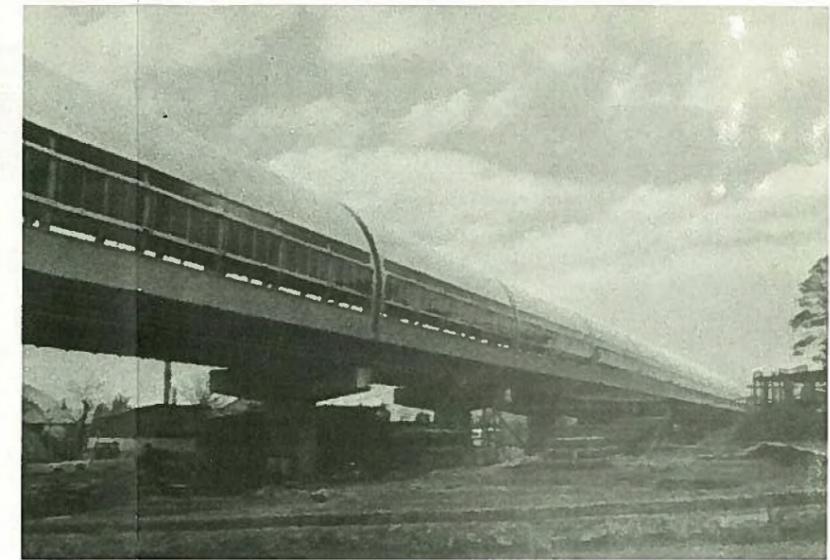


ELEVATED
GUIDEWAY
SIDE VIEW

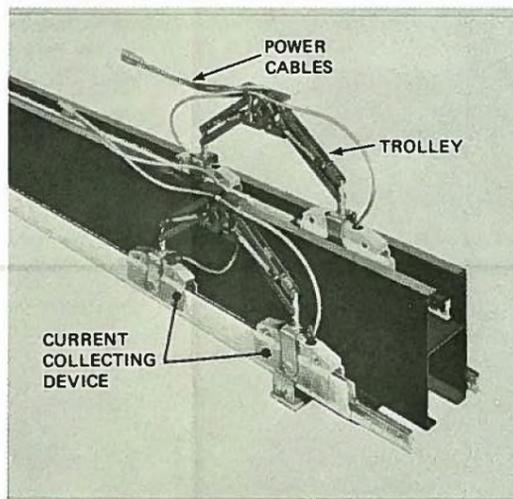


GUIDEWAY INTERIOR

SAPPORO



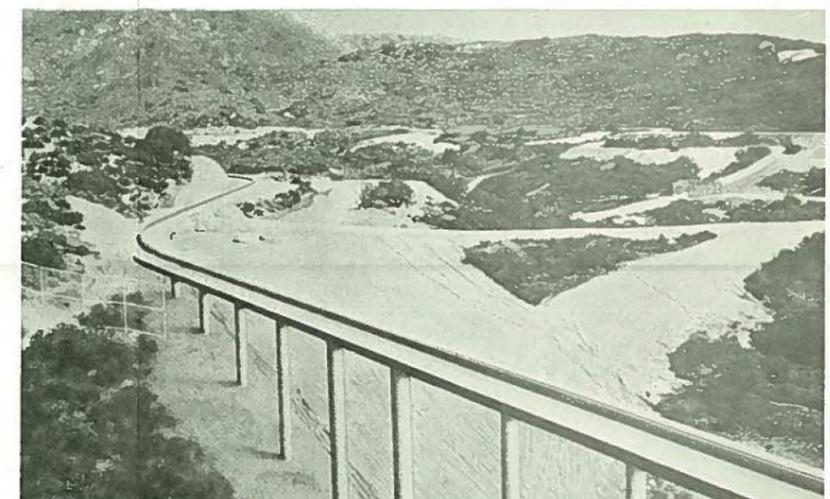
GUIDEWAY EXTERIOR



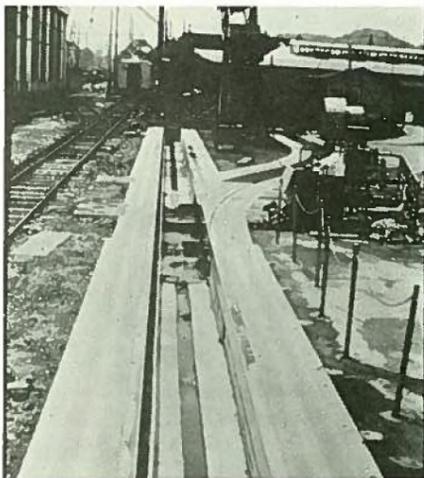
GUIDEBEAM
AND PICKUP

ROHR MONORAIL

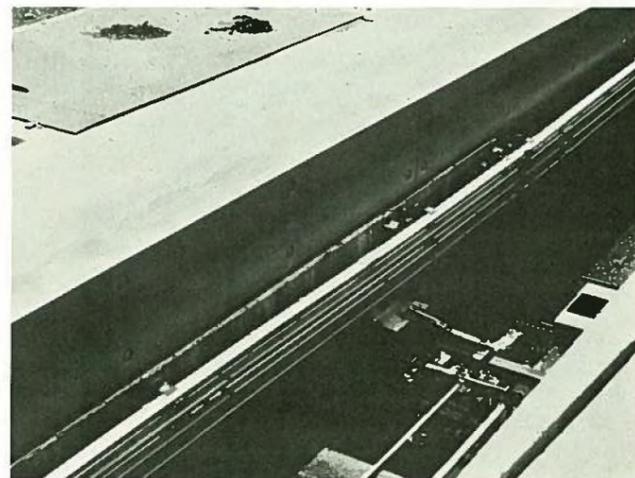
ELEVATED
GUIDEWAY



GUIDEWAY AT GRADE

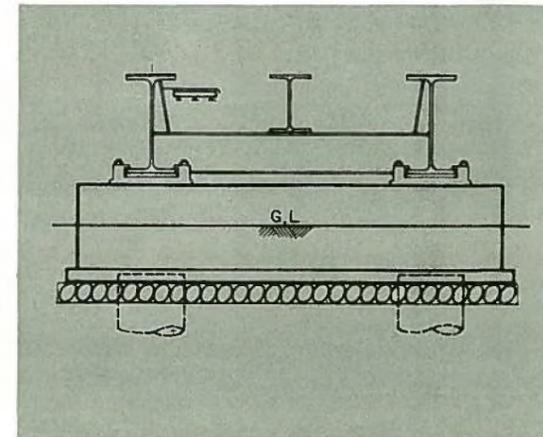
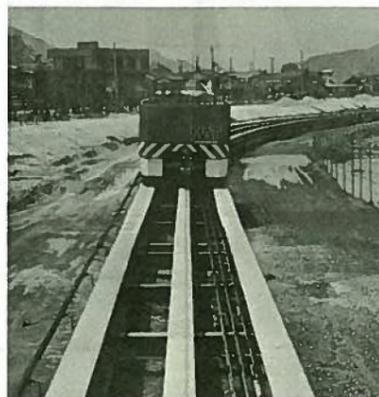


SLOT AND POWER RAIL



PARATRAN

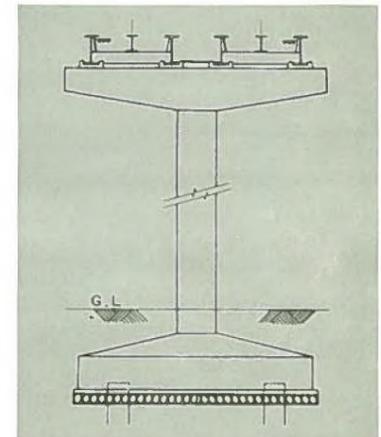
TEST TRACK AT GRADE



CROSS
SECTION

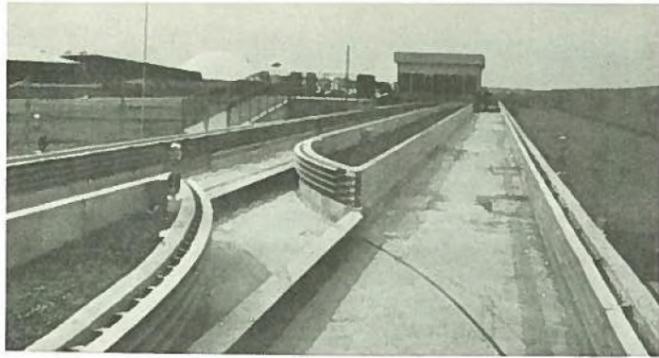
ELEVATED
STRUCTURE

MAT SYSTEM

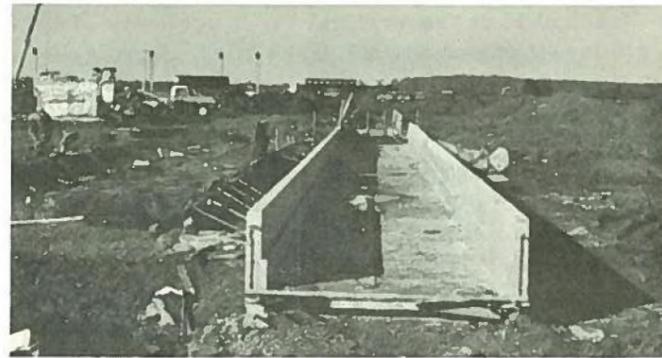


GUIDEWAYS FOR CENTER GUIDEBEAM
AND INBOARD GUIDANCE
FIGURE III-14

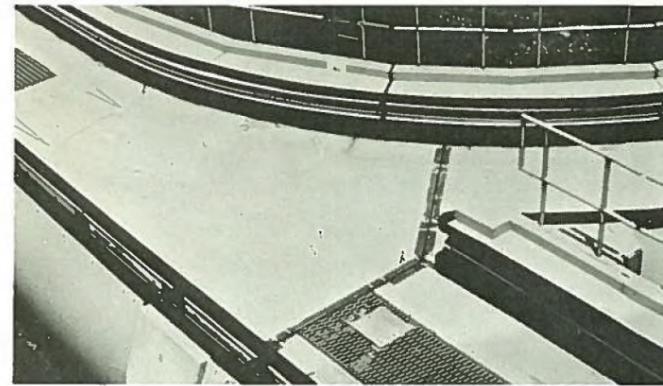
GUIDEWAYS FOR OUTBOARD GUIDANCE



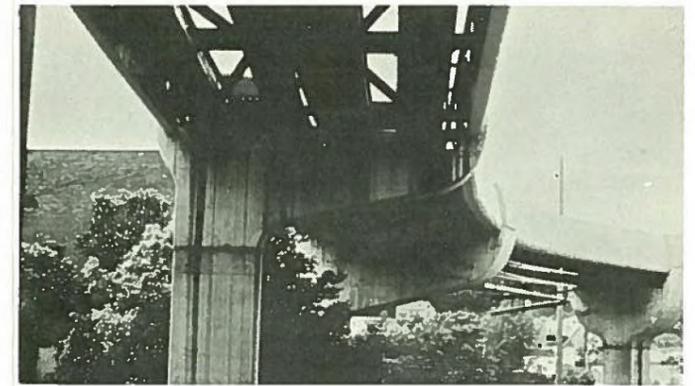
TRANSPO INSTALLATION



CONCRETE GUIDEWAY AT GRADE



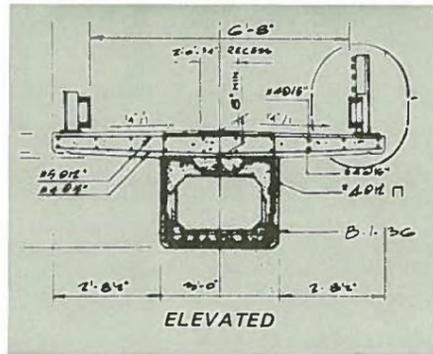
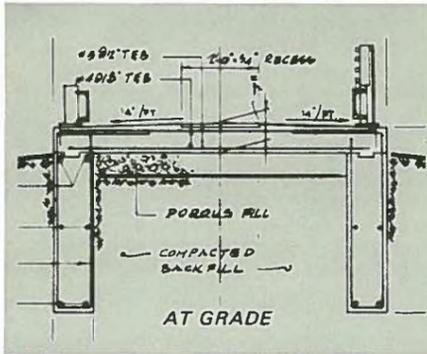
GUIDEWAY AT INTERSECTION
PRT, BOEING MORGANTOWN



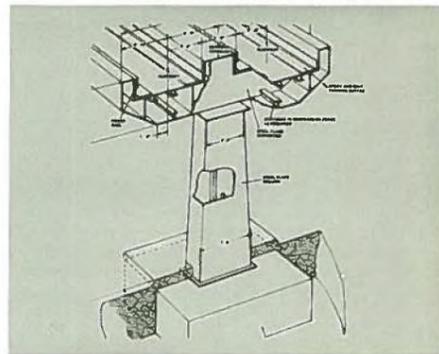
ELEVATED GUIDEWAY ON CANTILEVERS

DASHAVEYOR, BENDIX

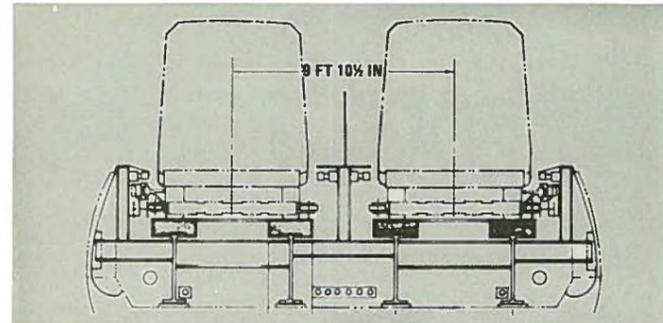
CONCRETE GUIDEWAY CROSS-SECTIONS



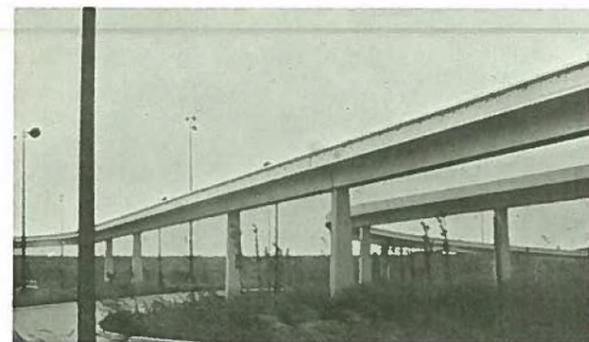
DOUBLE STEEL GUIDEWAY



CROSS-SECTION



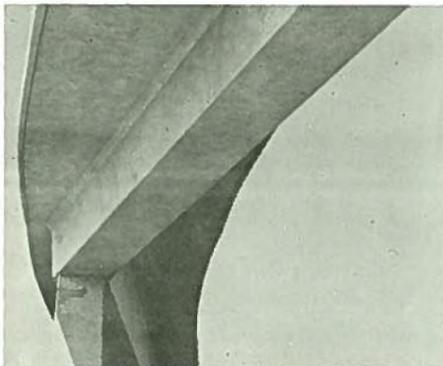
ELEVATED GUIDEWAY



ELEVATED GUIDEWAY

AIRTRANS, LTV

ELEVATED CURVE



GUIDEWAY CURVE



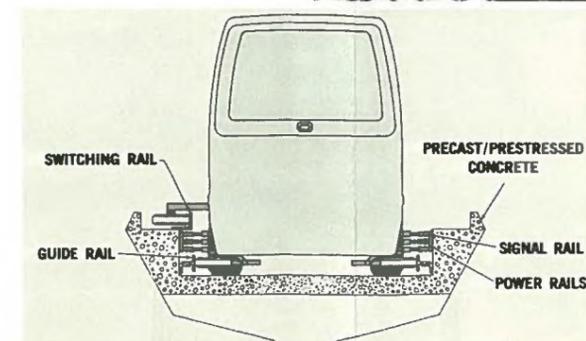
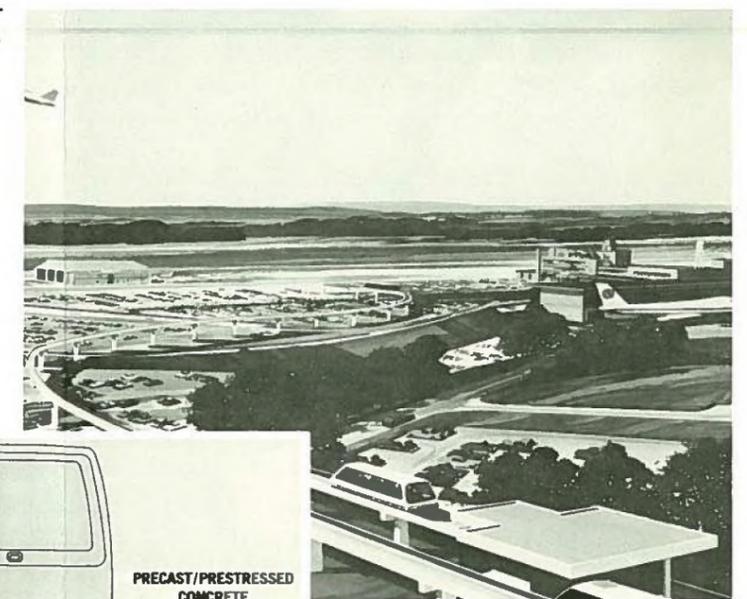
NEWTRANS



GUIDEWAY AT GRADE

ARTIST'S CONCEPT
ELEVATED GUIDEWAY

ACT, FORD



CONCRETE GUIDEWAY SECTION

GUIDEWAYS FOR OUTBOARD GUIDANCE
FIGURE III-15

SWITCHING

CATEGORIES

During the survey, a wide variety of switch concepts was encountered. These concepts were organized into six basic switching categories as follows:

- o LT-Lateral Translation of Guide Beams: Guide beams are moved horizontally in a direction perpendicular to the axis of the guideway. In this manner, tangent and turn-out switching surfaces are moved into operating position. The concept is applicable mainly to configurations in which the guidance surfaces are above the plane of the running surfaces and, therefore, must be entirely removed for proper switching operation.
- o LR-Lateral Rotation of Guide Beams: Guide beams are rotated in a horizontal plane about a pivot at one end of the beam. The pivot axis is perpendicular to the guideway running surface. This concept is applicable if the guide beams are either above or below the running surface so that the pivot end does not interfere with the vehicle during switching operations.
- o VT-Vertical Translation of Guide Beams: Guide beams are alternately translated vertically out of a position flush with the guideway surface into the switching position. This concept is applicable mainly to configurations in which the guide beams are above the guideway running surface.
- o VR-Vertical Rotation of Guide Beams: This is a unique form of switch in which the main mechanism is essentially a rotating drum whose axis is below the running surface level and parallel to the longitudinal axis of the guideway. This drum mechanism rotates through an angle of 180 degrees. In one extremity of this rotation, tangent guide beam and running surface elements are in place in the guideway. At the other extremity of rotation, the corresponding turnout elements are in place.
- o OBF-On Board Switching With Fixed Guide Beam: Active switch components are all mounted aboard the vehicle. These normally take the form of horizontally oriented auxiliary wheels. A mechanism onboard the vehicle moves these wheels from one position to another. Positioning of these wheels determines with which passive guideway element (usually a capture channel) the switching wheel on one side of the vehicle engages. The process of engagement determines whether the vehicle is guided through the tangent or turn-out portion of the switch.

- o OBM-On Board Switching With Moveable Guide Beam: In this variation of the OBF switching system, a moveable element in the guideway guide beam either remains flush with the beam or rotates inward toward the center of the guideway. The position of this moveable guideway element determines which of the two capture channels are engaged by the auxiliary switching wheels mounted on the vehicle. Engagement determines the course of the vehicle through the switch as in the case of the OBF concept.

The switching categories just described are illustrated on Figures III-16 through III-19. Since more than one switching concept is applicable to a given guidance concept, these illustrations are organized according to switching categories.

LATERAL TRANSLATION

Lateral Translation (LT) switching is used on the Westinghouse and Tokyu Paratran systems. These are illustrated on the left-hand portion of Figure III-16.

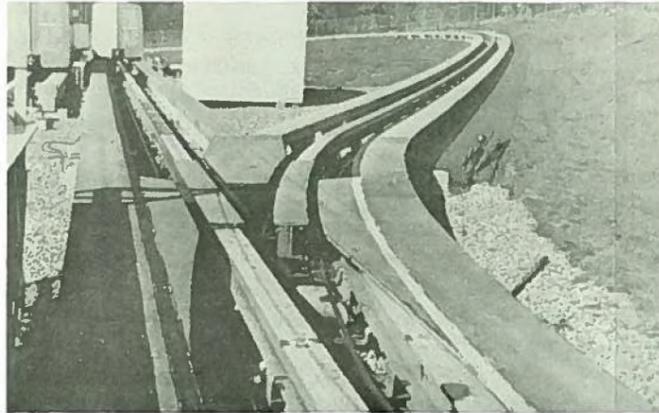
Westinghouse has designed and constructed at least three types of switches. For the initial South Park installation, the only switch was a transfer table used to move single vehicles from the storage area to the main guideway. For Phase II of the South Park Project, a switch consisting of two guide beam sections (one straight and one curved) was installed. The two beam sections were fastened into a unit assembly which could be moved laterally to alter the directions of the route.

Westinghouse was not satisfied with the South Park switch; the method of manual operation was too awkward and slow; some of the design details were unacceptable in terms of reliability or smoothness of operations; and some vibratory buildups in switch members were experienced. Westinghouse has since developed a prototype switch on which the tangent-curved guidebeams are pivoted (type LR) on the "Y" end of the switch; the prototype has been tested for reliability, but has not been installed for operational testing (right-hand portion of Figure III-16).

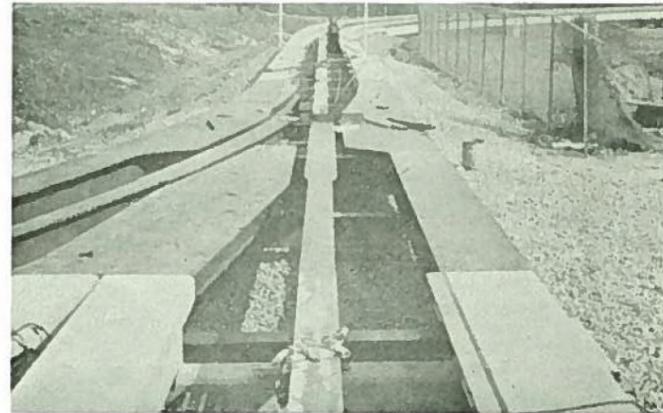
The Lateral Translation switching concept is also used on the Paratran system but, in this case, in conjunction with the IBG type of guidance configuration. The movable switch element is a triangular-shaped, fabricated steel box which is moved laterally across the guideway to present either a tangent type guidance surface or a turnout guidance surface as shown.

SWITCH CONCEPTS LT AND LR

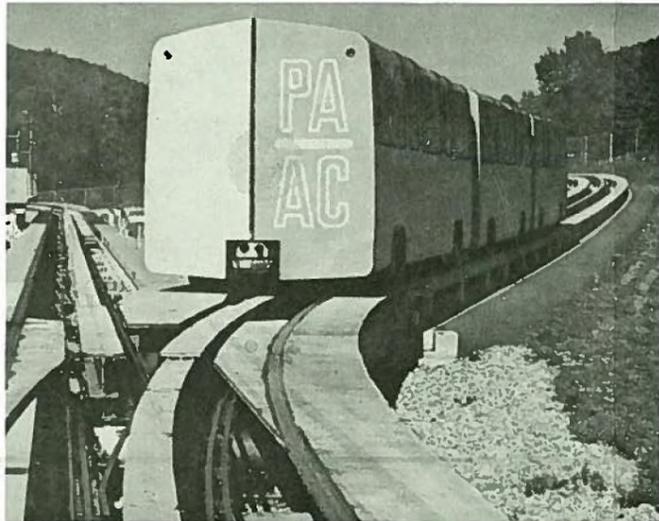
LATERAL TRANSLATION OF GUIDEBEAM (LT)



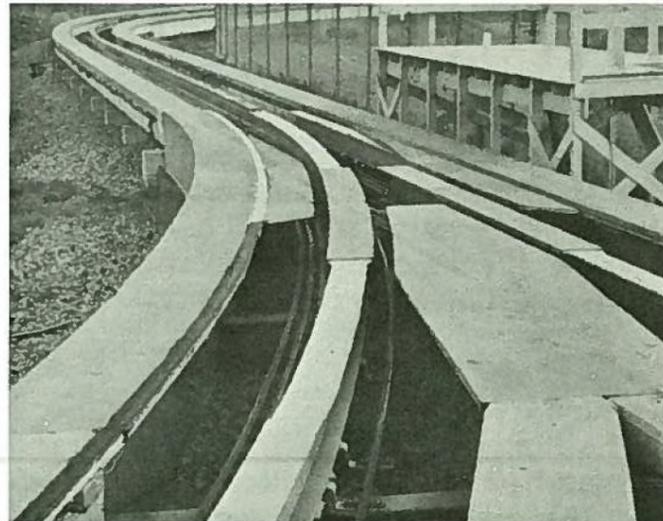
SWITCH LOOKING NORTH TANGENT POSITION



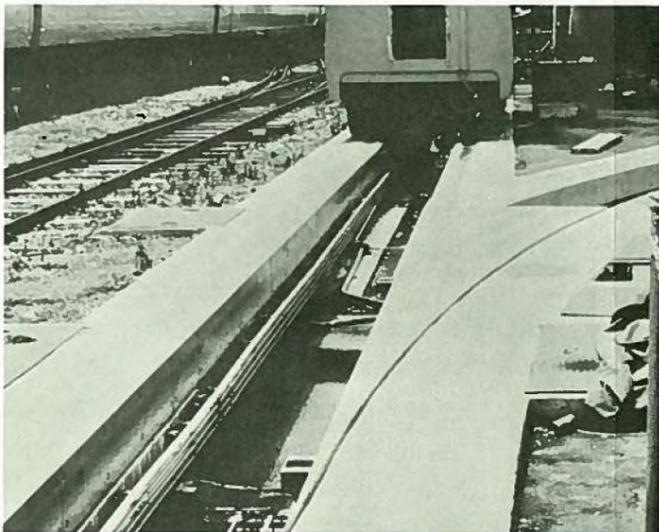
SWITCH LOOKING SOUTH TANGENT POSITION



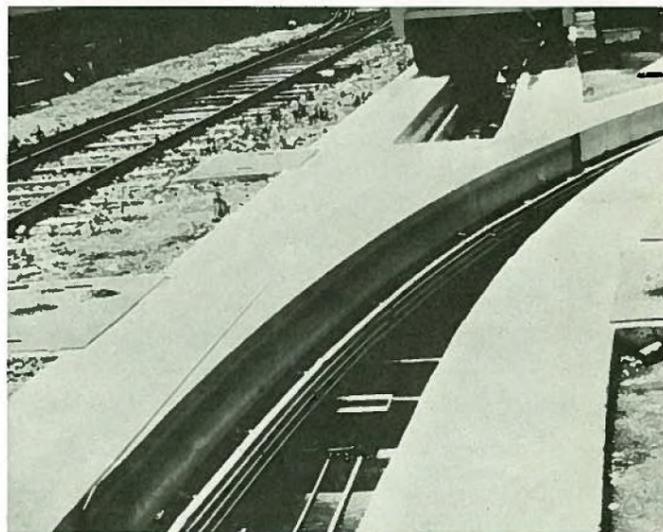
SWITCH LOOKING NORTH TURNOUT POSITION



SWITCH LOOKING SOUTH TURNOUT POSITION
WESTINGHOUSE TRANSIT EXPRESSWAY



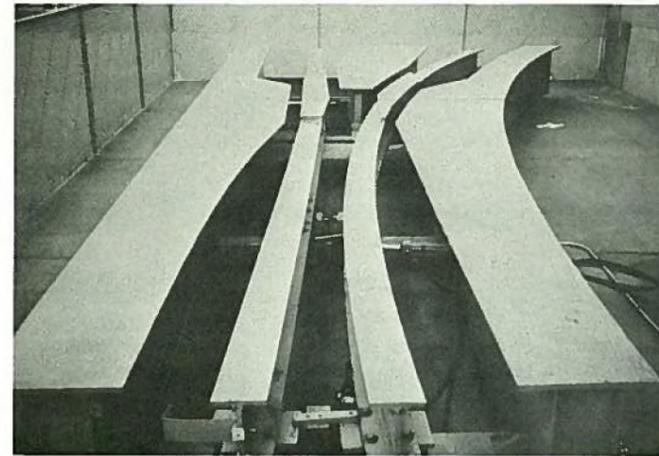
TANGENT



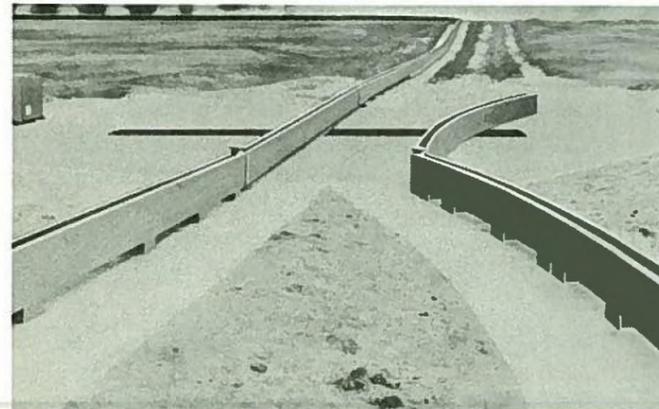
TURNOUT

PARATRAN

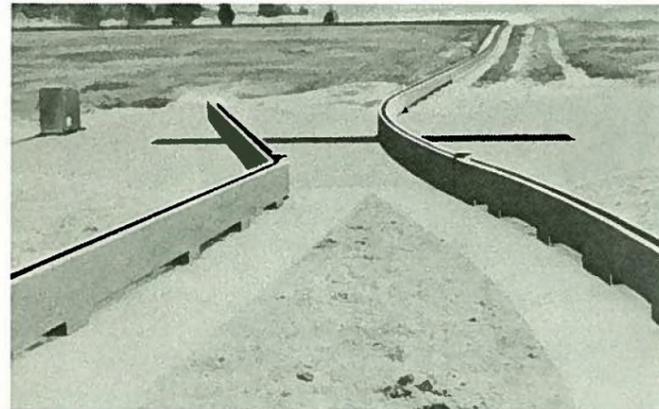
LATERAL ROTATION OF GUIDEBEAM (LR)



WESTINGHOUSE, PROTOTYPE SWITCH

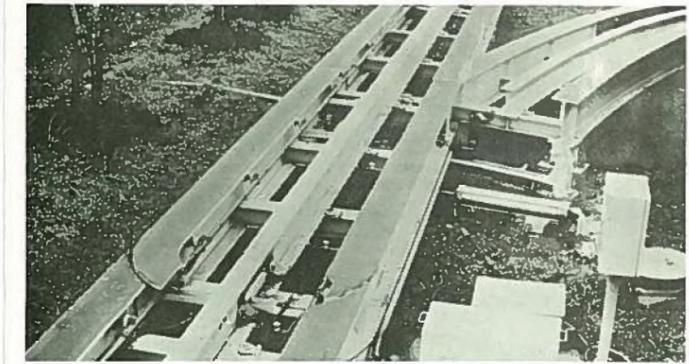


STRAIGHT-THROUGH ROUTE

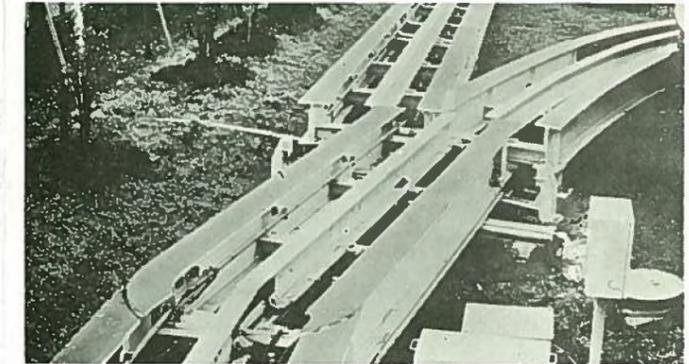


DIVERGING ROUTE

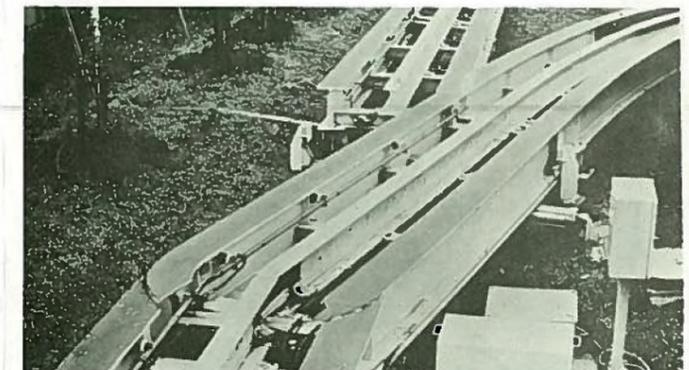
ROHR SWITCH



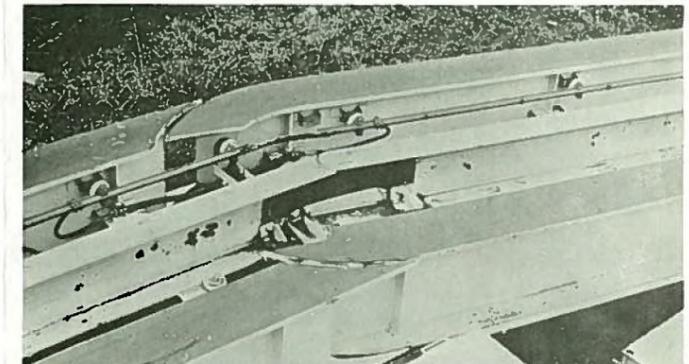
TANGENT POSITION



MIDSTROKE



TURNOUT

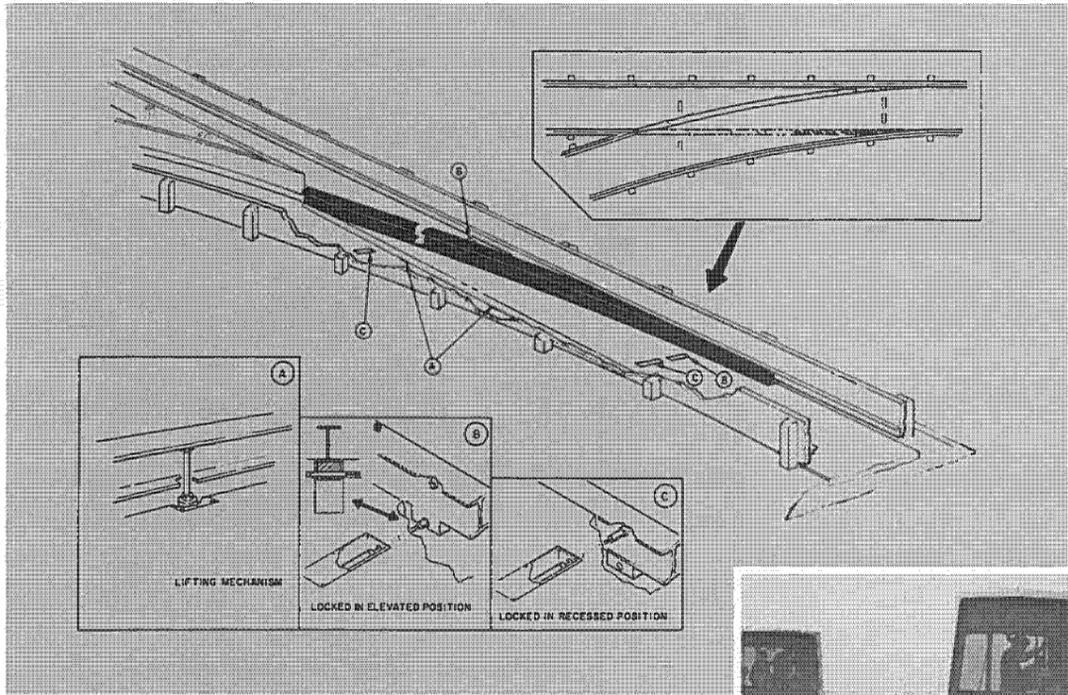


FLEXIBLE JOINT

VONA SWITCH

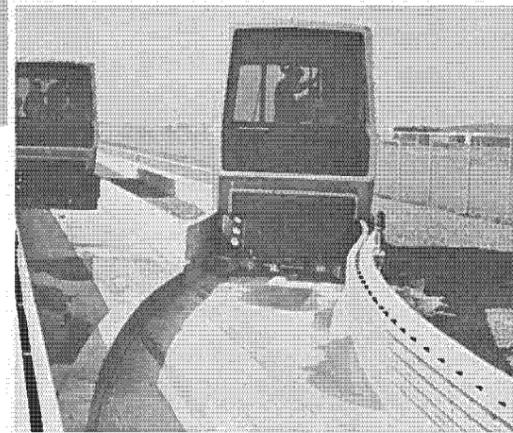
SWITCH CONCEPTS LT AND LR
FIGURE III-16

SWITCH CONCEPTS VT AND VR



DASHAVEYOR, BENDIX

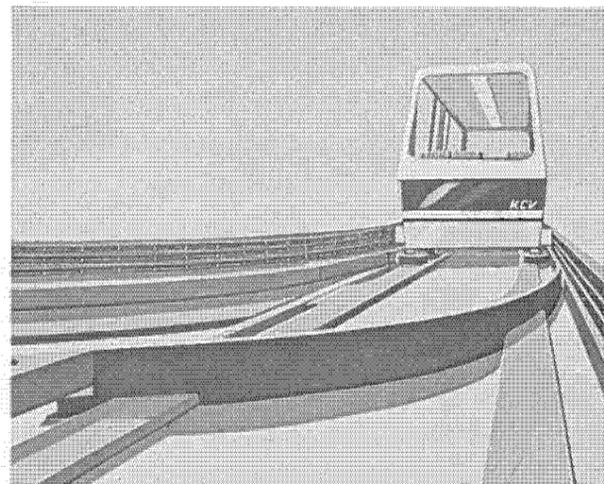
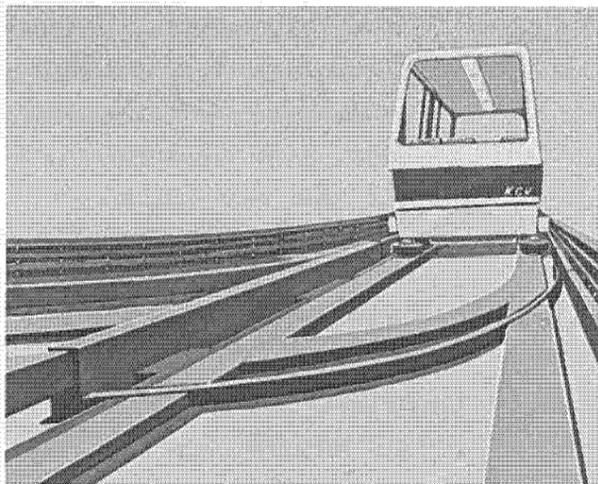
GUIDEWAY DIVERTER
TURNOUT POSITION



COMPUTER CONTROLLED VEHICLE SYSTEM, KAWASAKI
VERTICAL DISPLACEMENT OF GUIDE BEAM

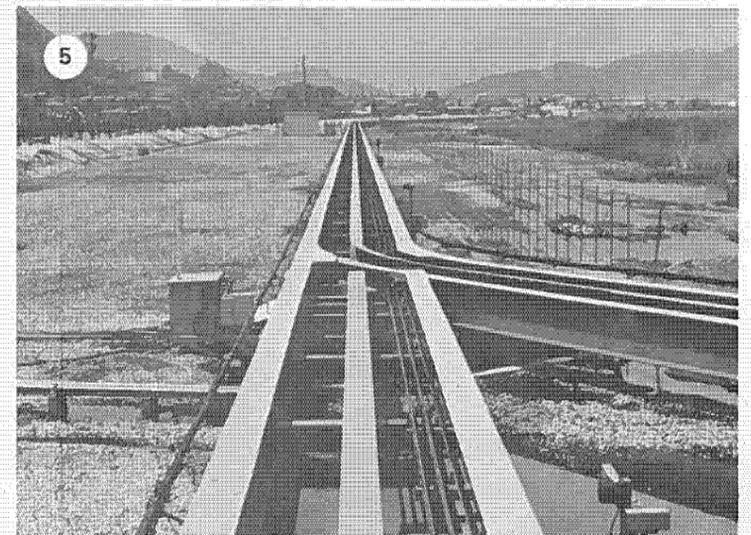
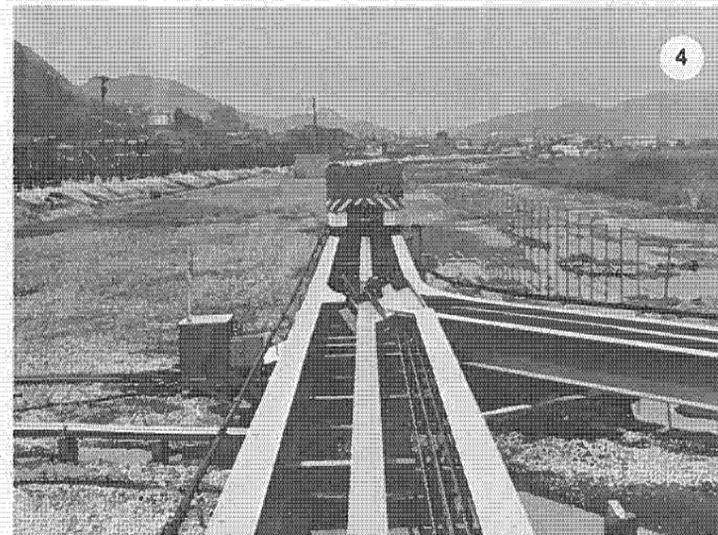
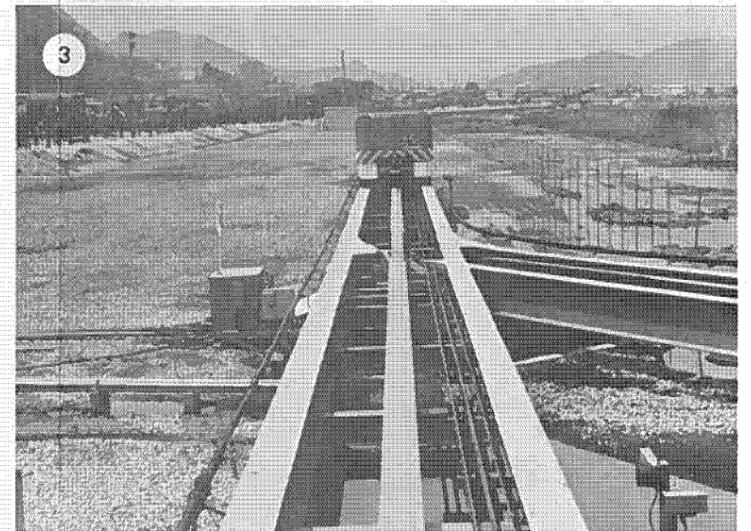
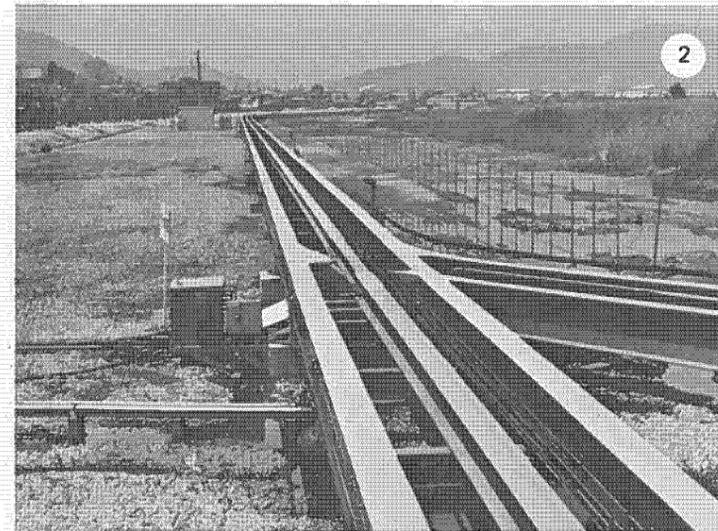
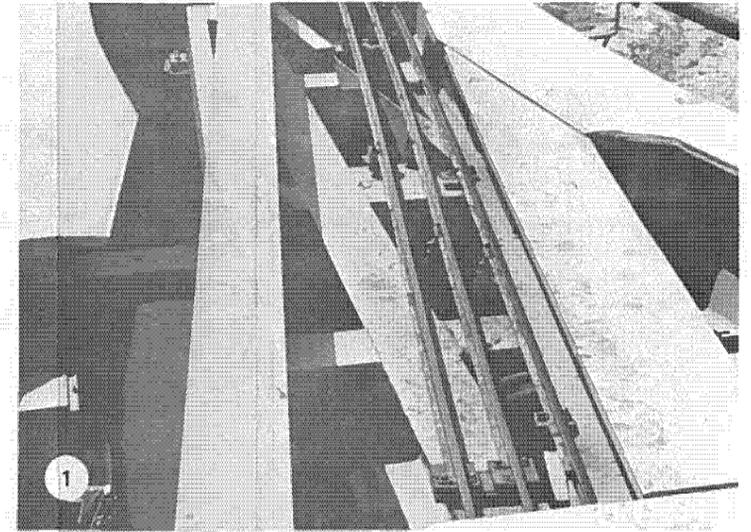
TANGENT

TURNOUT



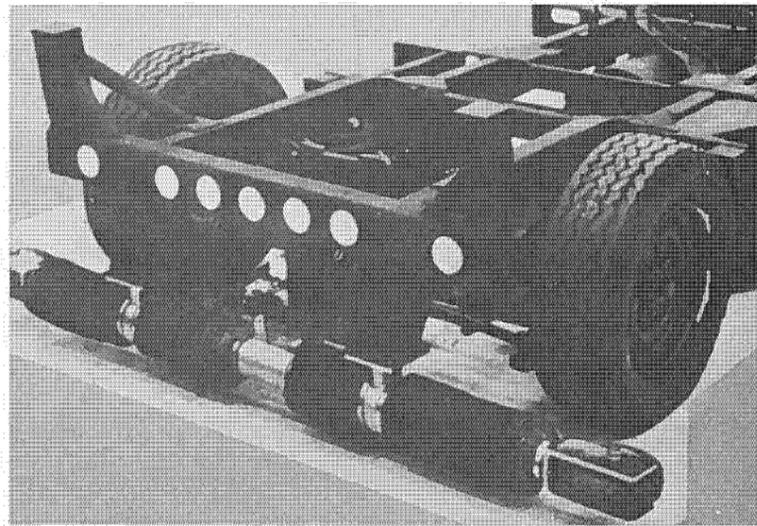
MAT SYSTEM

1. TANGENT, CLOSE-UP
2. TANGENT
3. STARTING ROTATION
4. ROTATION, PARTWAY
5. TURNOUT

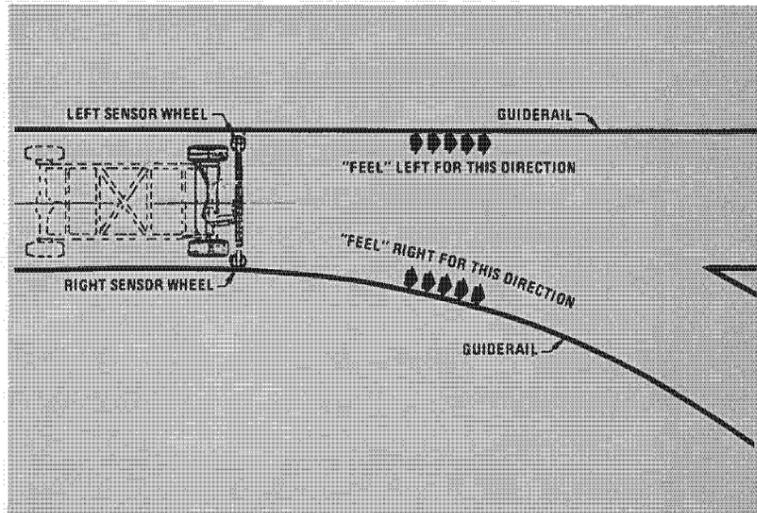


SWITCH CONCEPTS VT AND VR
FIGURE III-17

ONBOARD SWITCH CONCEPTS—FIXED GUIDEBEAM

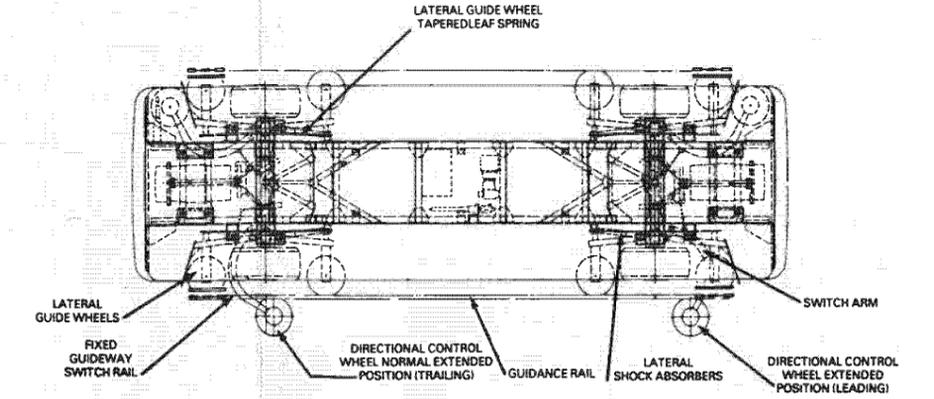
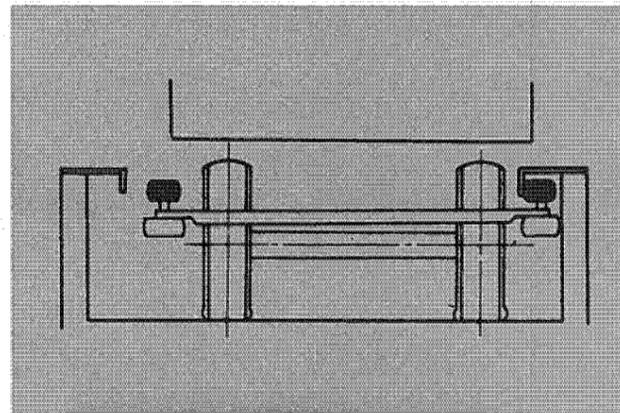
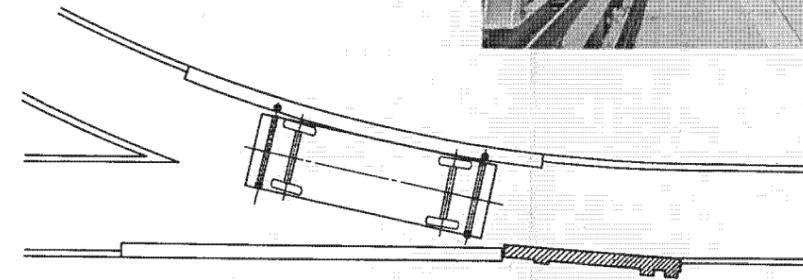
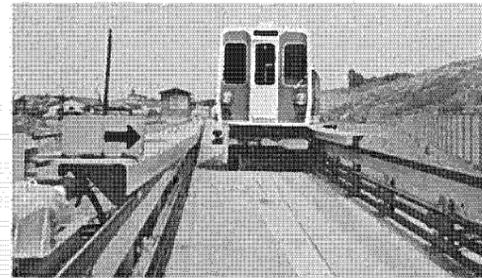
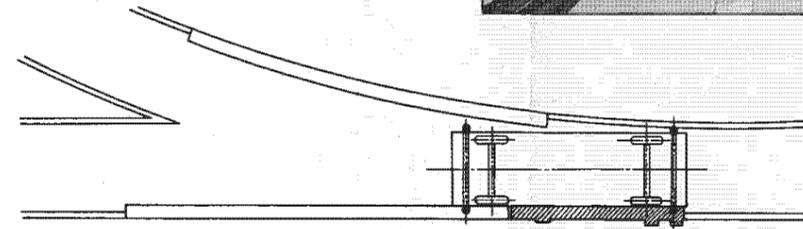
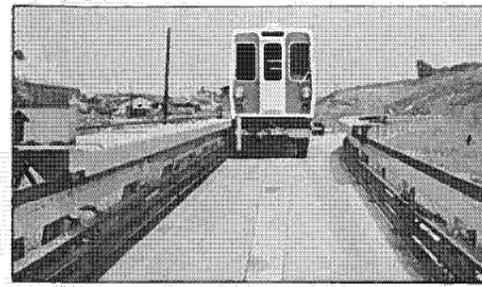


BOEING MORGANTOWN PRT



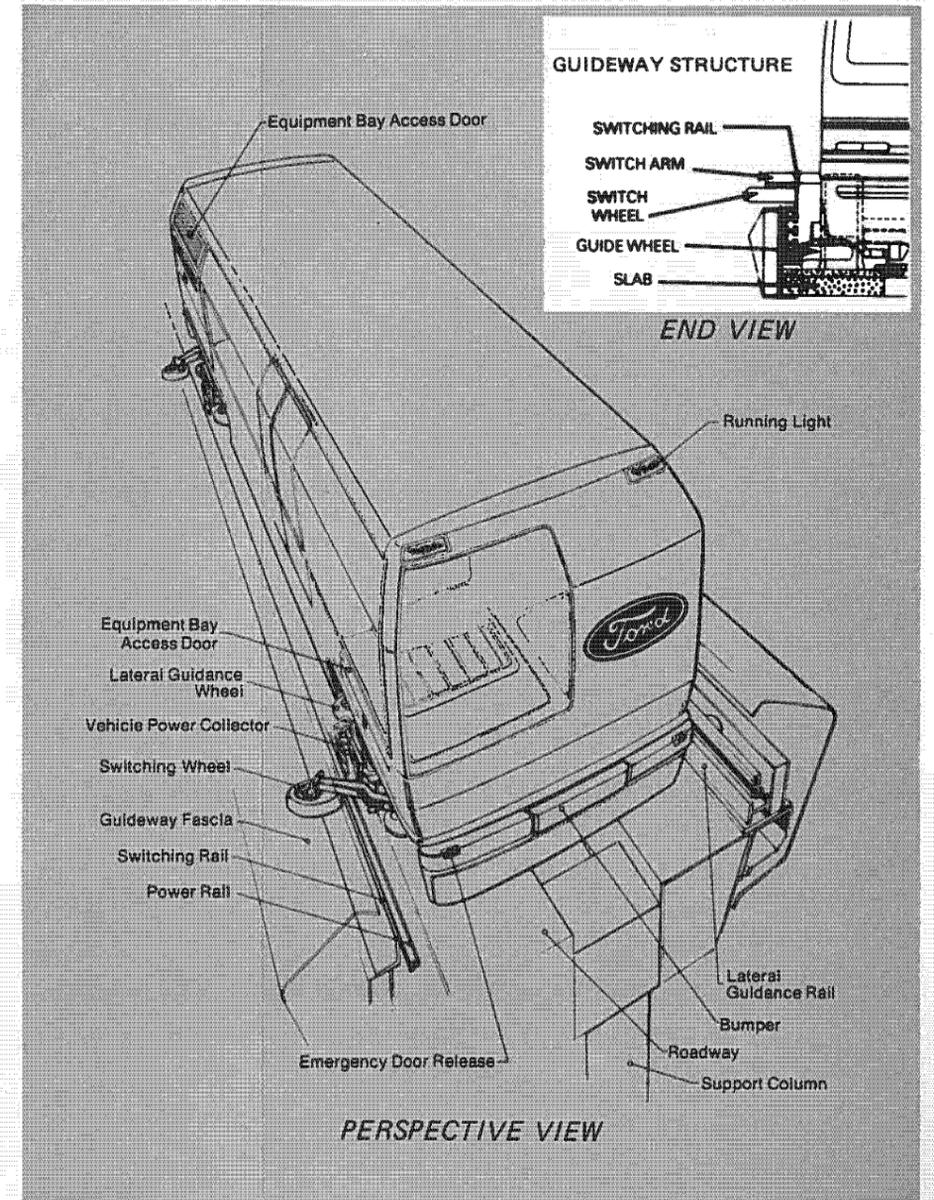
GUIDEWHEELS PRESS AGAINST SIDEWALLS (NO LOCK-ON)

NEWTRAN SYSTEM



PLAN VIEW

FORD ACT

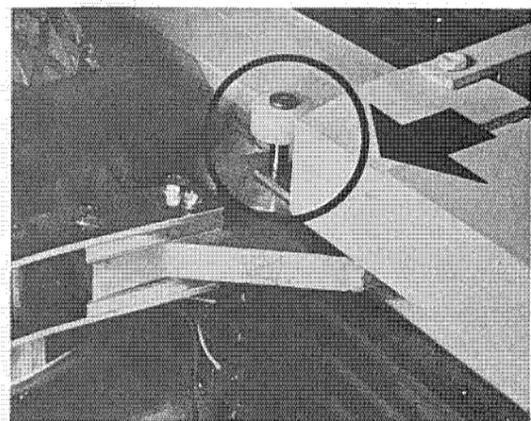


PERSPECTIVE VIEW

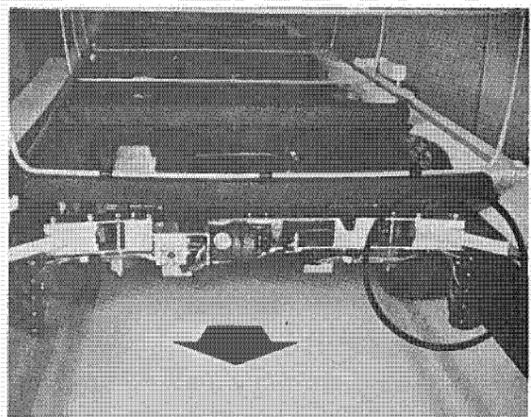
ONBOARD SWITCH CONCEPTS
FIXED GUIDEBEAM
FIGURE III-18

ONBOARD SWITCH—MOVABLE GUIDEBEAM

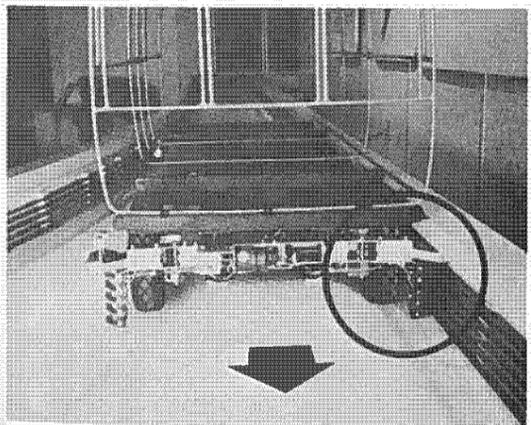
AIRTRANS, LTV



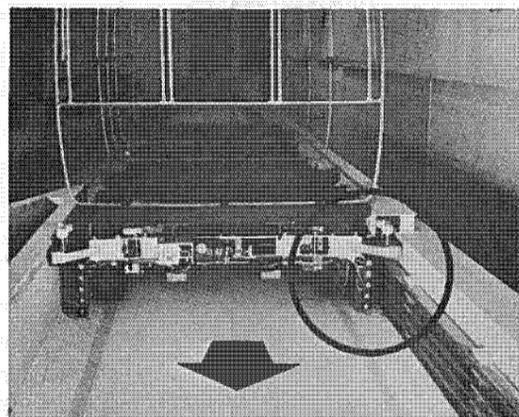
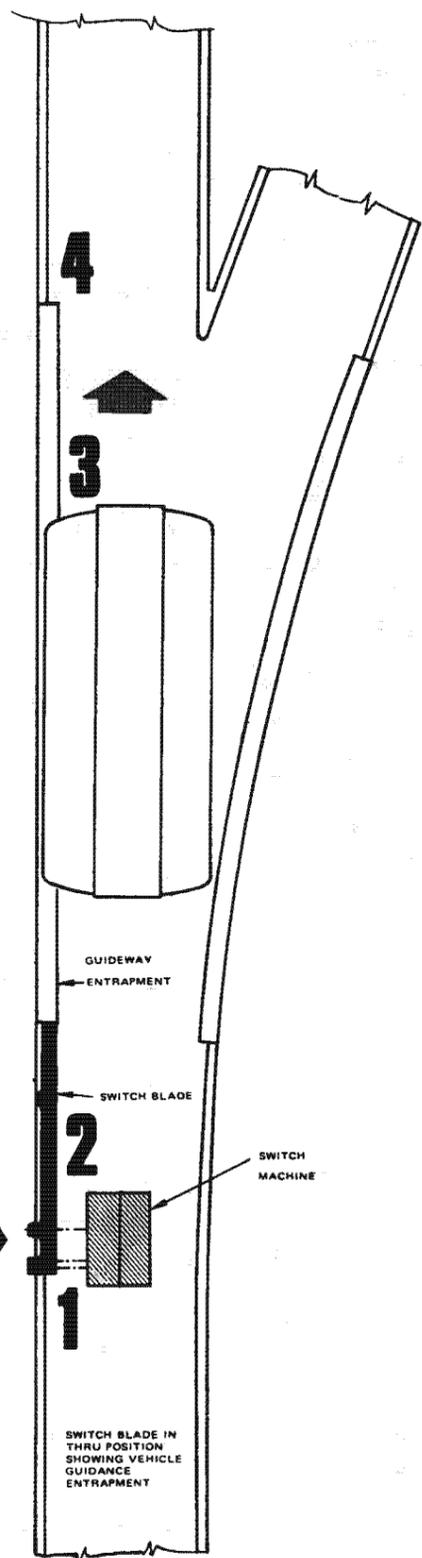
1



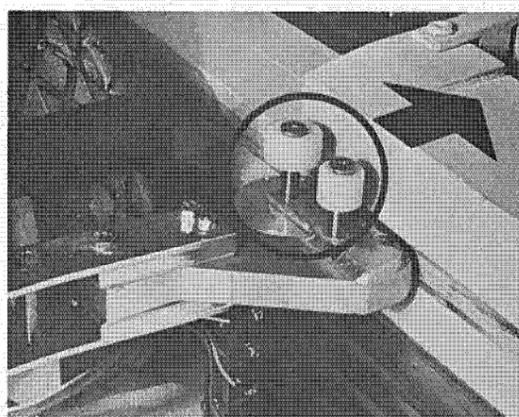
2



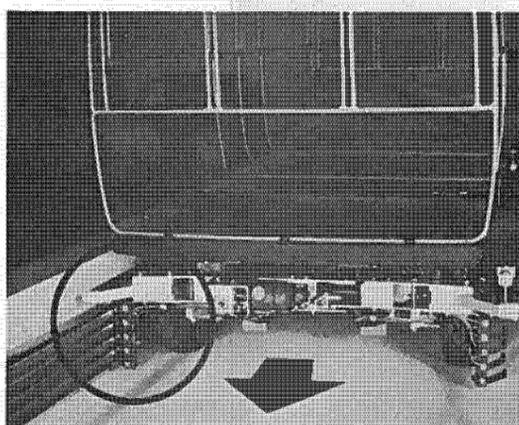
3



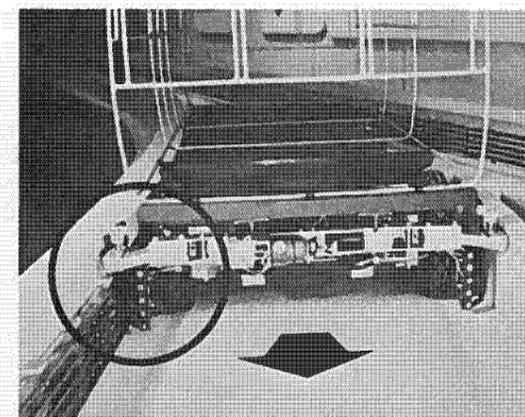
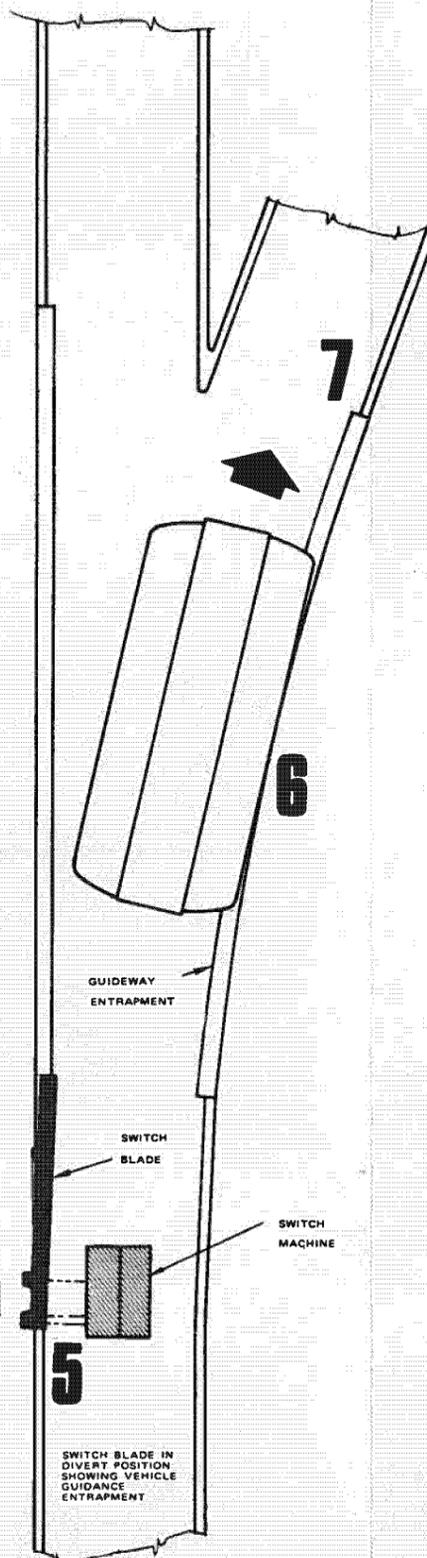
4



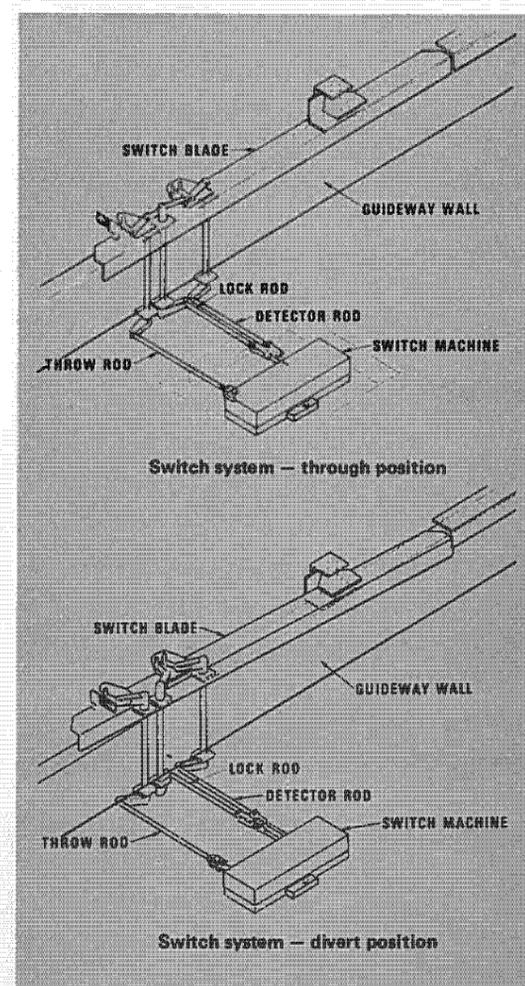
5



6



7



ONBOARD SWITCH
MOVABLE GUIDEBEAM
FIGURE III-19

LATERAL ROTATION

The Lateral Rotation (LR) switch concepts are shown on the right-hand portion of Figure III-16. In addition to the new Westinghouse switching system already described, these include switches for the VONA and Rohr systems. All of these are center guide beam systems, but the details of the switches differ. The Rohr switch operates with a guide beam location above the guideway running surface, and only the guide beams rotate. The switch consists of two movable sections of guide beams, designed to swing together so either a curved or straight section is in place. The switch can be designed for reasonably rapid operations (Rohr claims 8 seconds operating time); however, most installations have switches with much longer operating times, located in maintenance and storage areas only and not on the main guideway. In the Westinghouse concept, the guide beam is below the running surface, but the running surface elements have been flared so that, in this case also, only the guide beam rotates.

The movable element of the VONA switch is a unit containing straight sections of the center guide beam and running surfaces, all of which rotate in unison. The series of three photos starting at the top right of Figure III-16 shows a switch sequence from tangent position (top photo) to turnout position. Because of the lack of any curvature in the switch elements, the change in direction occurs abruptly at the switch pivot points. This abruptness has been somewhat alleviated by insertion of a small, flexible steel strip in the guide beam pivot point as shown in the illustration on the bottom right of Figure III-16. However, with this configuration, switch through speed in the turnout position must be very low. This switch is only suitable for switching vehicles to maintenance and storage areas, and is not suitable for operational use.

The Metro switch (not shown) is no more than a conventional railroad switch, raised slightly above the level of the running slab so that the steel wheels on the vehicle are engaged in the switching area.

VERTICAL TRANSLATION

The Vertical Translation (VT) concept is illustrated on the left-hand side of Figure III-17. Systems incorporating this concept are the Bendix Dashaveyor systems, the Kawasaki KCV system, and the Sapporo system, also developed by Kawasaki, but not shown. In these systems, side guide walls, either tangent or curved, translate up into position from the guideway surface. The vehicle guide wheels remain in a fixed position, and simply engage whatever guide walls are in place. Switch operating time for the KCV system is 3 seconds, while the operating time at Sapporo is somewhat longer because of the switch's much larger size. Problems are being

experienced because of changes in ambient temperature. Limit switch problems are also occurring. Also, the basic design concept requires that the two switches of a switchback arrangement be in series, which requires considerable guideway length. Kawasaki is working on a concept (scissors switch) that will permit the two switches to be superimposed to reduce length.

It should be noted that both the tangent and turnout guide walls of the switch must be aligned with the guide walls of the guideway when each switch element is in the operating position. This alignment requires lateral, as well as vertical, motion of the switch elements during changeover, which complicates the whole mechanism.

VERTICAL ROTATION

Vertical Rotation (VR) switching is exemplified by the unique Mitsubishi MAT concept shown on the right-hand side of Figure III-17. The sequence of illustrations shows the switch in its tangent and turnout positions, as well as in partly rotated positions. Total switch actuating time is 6 seconds. Interlocks are provided so a vehicle cannot enter the switch until it is locked in one position or the other.

ON BOARD WITH FIXED GUIDE BEAM

On Board Switching With Fixed Guide Beam (OBF) is illustrated on Figure III-18. The Boeing Morgantown and Ford ACT systems represent variations of this basic switching concept.

In the Morgantown concept, the guide wheels also accomplish the switching function. These wheels, mounted at the front of the vehicle only, act as vehicle position sensors. The support wheels and sensing wheels are instructed to follow one guide wall or the other. The support wheels steer toward this wall. The sensor wheels "feel" the wall and control the vehicle position relative to the wall by providing steering commands to the support wheels. The vehicle is not "mechanically tethered" during any part of the switching process, and an error or malfunction in the control signal is apt to cause a head-on collision with the guideway dividing structure.

On the other hand, the Ford vehicles are fully "mechanically" tethered" at all times. Switching direction is determined by the lateral positioning of a set of switching wheels, fore and aft, on each side of the vehicle. This positioning determines which side of the vehicle is captured by an entrapping channel, and, thereby, the direction of the vehicle through the switch.

ON BOARD WITH MOVABLE GUIDE BEAM

On Board Switching With Movable Guide Beam (OBM) is a hybrid, containing an active switching element both in the guideway and on board the vehicle. This class of switching is exemplified by the Airtrans concept shown on Figure III-19. In this concept, also, the switch wheels engage a switch rail; however, in this case the switch rail is movable rather than the wheel. The switch wheels are attached directly above the guide wheels, and the rail engages the wheels from above.

NOISE

Few reports on operational noise levels of rubber-tired transit system are available. During the survey, some measurements were made using a hand-held noise meter, at operating systems and at test tracks. A report compiled by the Mexico City Metro staff of noise measurements taken in that system was made available, and reports on noise measurements made in several European and Canadian systems were also consulted.

The Mexico City Metro is a particularly noisy system, because of the construction methods used and because the cars contain window openings to compensate for a lack of air conditioning. Observed noise levels on subway station platforms were in the 80 to 90 dba range; inside the cars the noise level was 80 to 85 dba. Noise levels observed in the Montreal Metro were only slightly lower on the platforms, although noise within the cars was as much as 5 dba lower than in Mexico. Similarly, noise at Sapporo was generally in the 75 to 80 dba range, and most of the noise in the vehicle interior was attributed to motor noise. The motors presently are mounted directly to the vehicle body rather than to the trucks, but the redesigned vehicles will have the motors on the trucks, thereby reducing interior noise levels.

On the U.S. and Japanese medium-capacity systems, the general range of vehicle noise levels was 70 to 75 dba. Intermittent levels about 5 dba higher are experienced during operation of air conditioning equipment. External noise levels varied from 65 to 75 dba 25 feet from the guideway, with substantial noise reduction effected by guideway sidewalls.

It must be recognized that most of the noise measurements were taken at test tracks or at operational systems for which extensive noise attenuation measures have not been incorporated. In all cases, the opinion was expressed by system operators and suppliers that considerably quieter operations were feasible, and observations of the relative silence of the modern, steel-wheel BART system confirm that quiet operation is attainable.

RIDE QUALITY

BACKGROUND

The modern automobile has established and demonstrated a high level of ride quality. Modern transit systems, which will have to compete with the automobile for patronage, must also exhibit a comfortable, high quality ride in order to enjoy good public acceptance. For this reason, attention was given to the ride quality characteristics of the systems surveyed. Some actual measurements had been made by the manufacturers and/or operators of some of the systems. In some cases these were made available; in others, the data were withheld either because it was felt to be proprietary or because the development and tuning of the suspension system had not yet been completed. Since it was impossible for the writers to make their own measurements of ride quality during the survey due to the complexity of such an undertaking, this evaluation of ride quality will be largely qualitative.

The quality of ride experienced by a passenger results from modifying the disturbances initiated by the vehicle-guideway interface with alterations imposed by the dynamics of the vehicle and its suspension, tires, guidance, braking, and propulsion systems. Therefore, in any consideration of ride quality, both the vehicle and the guideway must be considered.

RIDE QUALITY EXPERIENCED

On the large-capacity systems, the ride quality of the Mexico City and Montreal Metro systems would have to be rated low compared to the ride on a modern rail system such as BART, particularly in the lateral direction. (However, the ride on these Metro systems was substantially better than that experienced on a conventional bus or on older rail systems). In addition, in Mexico, there are localized spots in the tunnels where vertical accelerations are high enough to cause considerable discomfort. Measurements by the Metro staff have yielded vertical acceleration levels of 9 to 11 mph/sec in these places. The cause for this condition is not specifically known, but Metro staff opinion is that improper compaction of the soil is the cause. In addition, the

stepped nature of the power control of the Mexico City Metro causes corresponding steps in the acceleration profile, although this was not considered to be a serious shortcoming. The Sapporo system vehicle has an objectionable resonance at 8 to 9 hertz. This is being reduced to below 2 hertz in the redesigned vehicles. Ride quality characteristics are currently not being released by Kawasaki, the designer and manufacturer of the Sapporo rolling stock. In the opinion of the survey investigators, however, the ride quality of this system was significantly better than that of either the Mexico City or Montreal Metros.

With regard to the medium-capacity systems, the survey investigators were able to ride on the LTV Airtrans, Rohr Houston and San Pasqual, Ford Fairlane, Boeing Seattle test track, Westinghouse Sea-Tac, Japan Rolling Stock VONA, and Tokyu Paratran systems. The following comments are based on this experience, plus discussions with all of the manufacturers.

The ride quality of the LTV Airtrans system is considered to be relatively poor. The random accelerations in the transverse direction are very annoying. These are felt to be induced by side guide wall irregularities (the guide wheel tracks near the top of the sidewall) and inadequacies in lateral suspension and lateral steering input conditioning. Ride quality of the Rohr Houston system is, understandably, also very poor, due to the narrow gauge and very tight turn radii of the guideway to which it was retrofitted. Ride quality of the Rohr San Pasqual system is acceptable for its very low speed (typically 8 mph) and specific application, but would be inadequate at higher speeds because of lack of provisions for handling lateral disturbances, and the use of foam-filled tires.

The Ford Fairlane vehicle, as operated on the Cherry Hill test track, provided the best ride quality of any of the systems, in the opinion of the writers. This is perhaps not surprising due to Ford's vast background in small vehicle design and ride quality development. No ride quality measurements had yet been made on the test track which had only been in operation for 1 week at the time of the visit.

The VONA system displayed adequate ride quality, better than most systems, but inferior to the Ford Fairlane and perhaps the Boeing

Morgantown system. Japan Rolling Stock Company feels that the center guide beam concept gives better ride quality, particularly at higher speeds, but offered no comparative data to substantiate this opinion. Test track measurements on VONA had not yet been made but were scheduled. The ride quality criterion offered by Japan Rolling Stock Company is that the total disturbance vector not exceed 0.15 g. The adequacy of such a criterion is discussed in Appendix A.

The ride quality on the Tokyu Paratran system was also considered adequate. Tokyu stressed the importance of a dampening system between the guide wheels and the steering mechanism.

No experience was gained on the Kawasaki KCV system since the test track was not visited. Kawasaki uses the Japanese National Railway ride quality criteria. The firm claims the ride quality of KCV to be better than JNR curve No. 2, but feels that the level of curve No. 1 would be very difficult to meet. These curves are explained more fully in the section on criteria. Kawasaki also stressed the need for a damping system between the guide wheels and the steering mechanism.

Mitsubishi, as well, has given a great deal of attention to ride quality for the MAT system. Using combined JNR and NASA ride quality criteria, the company has established a target of 0.03 g maximum permissible disturbance over the range of 4 to 15 hertz. Mitsubishi claims to have attained this level on the test track.

The Boeing Morgantown ride quality specification requirements are 0.0625 g acceleration and 0.125 g/sec jerk in the longitudinal direction. Laterally, the specification requires a maximum acceleration of 0.12 g at 1 hertz down to 0.02 g at 4 hertz. The latter requirement matches that established for the BART system. Most of these requirements have been met in tests at Boeing's facility near Seattle, and the ride quality observed there is nearly as good as that observed at the Ford test track. The Boeing track was laid out over an existing asphalt parking lot, which caused the surface to have some irregularities. Even so, the ride was very smooth with regard to lateral acceleration and jerks, and only a small amount of vertical pitching was noticed.

The ride quality on the original South Park installation of the Westinghouse Transit Expressway was unsatisfactory in the lateral direction. The reason for this was claimed to be a lack of bending at the ends of curved guide beam sections caused by the bending

process used for these sections. This problem has been alleviated by cutting off the unbent ends of these guide beam sections after the forming process is completed. In addition, a lateral suspension system has been incorporated in some of the newer Westinghouse systems. Ride quality on Westinghouse's installation at the Seattle-Tacoma Airport was quite good, although some lateral jerks were still noticed on the curved track sections. Westinghouse personnel admitted that the Sea-Tac system did not incorporate their latest developments in suspension. Westinghouse now has a suspension research program under way. Targeted for this research is a three-axis resultant, maximum acceleration vector of 2 mph/sec.

IV. FINDINGS AND CONCLUSIONS

INTRODUCTION

While the descriptions and discussions contained in this document cover a wide range of subjects, emphasis of the study was placed on those parameters falling into the category of vehicle/guideway interface. Contained in this chapter are summaries of findings and conclusions on the subjects of Support, Switching, Guideways, Ride Quality, and Noise. Then the evaluation of the guidance and switching systems specifically applicable to the proposed Honolulu system is presented.

The summary of analyses of the criteria for ride quality and possible trend in vehicle weight as a function of size and capacity are presented in the Appendices.

FINDINGS AND CONCLUSIONS OF THE SURVEY

SUPPORT

Most of the high-capacity systems are supported on dual-axle bogies. Sapporo is a hybrid system incorporating single-axle, unpowered, steerable bogies. Because of vibration problems, these are being replaced with dual-axle bogies on a redesigned vehicle for a new subway line. Currently, the medium-capacity (lower speed) systems all incorporate single-axle bogies. Several manufacturers now have detail studies under way on the relative merits of single axles vs. dual axles for higher speed, medium-capacity, rubber-tired systems. To date, no such high speed system has been operated.

- o Tire life does not appear to be a problem. However, operating speeds above 30 to 35 mph will require specially tailored, more sophisticated tires than those used on present test and operational systems (such tires are now being developed). For medium-capacity systems with this speed capability, current practice appears to limit four tire vehicles to about 30,000 pounds design gross weight and eight tire vehicles to about 50,000 pounds design gross weight. Under these conditions, tire life approaching 100,000 miles should be attainable.

- o A means of frequent checking for loss of tire pressure needs to be incorporated in the high-capacity systems. This need has arisen from the serious consequences (e.g., fire) of continued operation following loss of tire pressure due to, say an undetected blowout. Tire pressures are checked automatically each time a vehicle arrives at a station. Some manufacturers of medium-capacity systems also stated the need for such a checking capability.
- o Several means of providing emergency support in event of a tire deflation were identified:
 - Dual tires at each axle end
 - Dual axle trucks
 - Single tires with dual chambers
 - Steel wheel inboard of tire
 - Steel wheel over center guide beam flange
- o The maximum speed capability of current foam tires is 30 to 35 mph. These tires probably have a potential of about 45 to 50 mph maximum speed. The application of the honeycomb racing tire principle to transit systems deserves further consideration. This type is currently used on the Kawasaki KCV vehicle. These tires are both foam-filled and pneumatically pressurized. They have the higher speed capability of the pneumatic tire plus the low speed support capability of the foam-filled tire in the event of loss of pressure. However, foam-filled tires have a significant detrimental effect on ride quality. For this reason and their previously discussed speed limitations, they should be avoided.
- o One of the biggest uncertainties resulting from the survey of rubber-tired systems is that of high speed capability. The operational high and medium capacity systems and those being developed are generally employing speeds of between 40 and 50 mph. The uncertainties of higher speed relate mainly to tire life and ride quality.

SWITCHING

- o The Vertical Translation (VT) type of switch, as used by Kawasaki KCV-12 and Bendix Dashaveyor with the Outboard Steered Axle

(OSA) guidance concept and by Sapporo Metro with the Center Guidebeam (CGB) guidance concept, appears to be slow, unwieldy, cumbersome, and costly. An adaptation of the Tokyu Paratran switching concept to the OSA guidance concept by orienting the translating plug to an elevation above the guideway running surface appears to be a promising solution to the switching of OSA guided systems. The Mitsubishi VR switch and the Westinghouse LR switch appear to be the best types for CGB guidance.

- o Active switches, guideway mounted, tend to be short (and therefore of small radius) because of weight, actuating power, and cost considerations. This means low run-through speed in the turnout position. This limitation is not as restrictive for the On Board Switching With Fixed Guidebeam concept, since the fixed guide beams can be made long and of large radius with no additional complexity and little additional cost.
- o On Board switching with fixed guidebeams appears the most promising concept for outboard guidance, particularly when the system contains many switch points and off-line stations and the vehicles operate individually. When the system uses multi-car trains and on-line stations with switches primarily used to reverse train direction, guideway switches show greater promise.
- o Rubber-tired systems can be sensitive to irregularities in the guidance surfaces. Such irregularities are probably more difficult to control during construction in the case of outboard OBG and inboard IBG guidance concepts than for the center guide beam concept. Where the OBG concept is used, the guide wheel contact should be near the base of the sidewall. In addition, a separate sidewall guidance element should be carefully aligned and installed as the last step in the construction of the guideway.
- o The center guide beam is probably the simplest to align properly because it is a single element. The other types of guidance have two elements which have to be aligned relative to each other, as well as absolutely.

GUIDEWAYS

- o The general concepts for guideway configuration usually follow from selection of the guidance concept. Designers are faced with a choice of material and fabrication technique, e.g., concrete poured in place, prestressed prefabricated concrete erected in place, prefabricated steel erected in place, etc. Such choices

depend on the physical characteristics of the site, vehicle loads, local labor conditions, local material costs, shipping costs, and many other system specific factors. During the survey, no special guideway technologies were identified, perhaps with the exception of epoxy grout used for surfacing both concrete and steel running surfaces.

RIDE QUALITY

- o With few exceptions, the ride quality of the systems surveyed was rated as fair. Several of the manufacturers are engaged in R&D programs aimed at improving the ride quality of their systems.
- o Ride quality results from the characteristics of both the vehicle and the guideway. The smoothness and accuracy requirements of the guideway should be carefully specified and provided to the vehicle supplier as interface input data for the vehicle design. Guideway accuracy requirements also should be specified in terms permitting compliance verification by measurements on the completed guideway.
- o The consensus of opinion, reasonably backed up by experimental observation, is that carefully designed lateral suspension systems are required to achieve good ride quality.
- o There is great disparity in proposed criteria for ride quality. Based on the limited investigation accomplished during the current survey, the Japanese National Railway criteria (type A for vibrational criteria and type B for single incident disturbance criteria) should be used for preliminary design purposes.

NOISE

- o Generally, vehicle interior noise levels were too high for normal conversation on the high-capacity Metro systems, particularly at their maximum speed of 45 mph. Sizable contributions to the noise level came from open windows, open ventilators, and vehicle body-mounted equipment. Careful treatment of these noise sources could have reduced the observed interior noise level of about 80 to 85 dbA by 10 to 15 dbA. Equipment noise also contributed to the noise levels of medium-capacity systems. It is likely that further development could reduce these observed levels of 70 to 75 dbA by 5 to 10 dbA.

EVALUATION OF THE GUIDANCE AND SWITCHING SYSTEMS

APPLICATION TO PROPOSED HONOLULU SYSTEM

One of the crucial areas of vehicle/guideway interface is the selection of the guidance and switching configuration which is vital to both the vehicle and guideway design. Various concepts of guidance and switching are available and being used for rubber-tired vehicles as previously described in this report. Based on the information developed from the survey, an evaluation was made of the available guidance and switching systems applicable to the Honolulu system.

Since rubber-tired vehicles are being developed and used for a wide range of transportation system concepts, e.g. PRT, people mover, and trunk line systems, it is necessary to define the critical design parameters of the proposed Honolulu system. The following section will provide the background and general description of the system.

DESCRIPTION OF THE PROPOSED SYSTEM

The basic rapid transit system proposed for Honolulu is a 23-mile trunk-line, fixed guideway system running from Pearl City to Hawaii Kai.^{2/} The system has 21 stations and is proposed to operate in the conventional transit mode, with every train stopping at each station. The proposed system utilizes intermediate-capacity (36 seats and about 36 standees) rubber-tired vehicles, operating in 2-car to 10-car train consists.

Projected peak-hour patronage volume for 1995 is approximately 18,000 passengers in each direction, and the system design capacity required would be up to 30,000 passengers per hour. 10-car trains operating at 90-second headway would have the required capacity.

The proposed guideway configuration incorporates switches beyond the two terminus stations (Pearl City and Hawaii Kai) to allow trains to reverse directions onto the parallel tracks. Similar turn-back switches will be located beyond the Halawa and University Stations which may be the termini of the first stage guideway constructed. In addition, emergency cross-overs will be available for the relatively rare event of bypassing a disabled train or a section of guideway under repair; switches will also be needed at the entrance and exit of the maintenance and storage facility.

Several operational concepts in addition to the recommended conventional transit mode have been analyzed. These concepts include extensive utilization of off-line stations in express/local train service throughout the system,^{5/} provision of bifurcation branch line service to activity

center such as Waikiki, Honolulu International Airport (HIA), and the University of Hawaii,^{6/} and provision of a special air-passenger transfer service between HIA and the Waikiki hotel district.^{7/} As concluded in these studies, neither the off-line station concept nor the branch line concepts appear economically feasible; however, the HIA-Waikiki transfer service does appear promising, and it is recommended that provisions be made in the initial transit system for eventual incorporation of such a transfer service.

EVALUATION OF SWITCHING CONCEPTS

There are two basic switching concepts - on-board switching with fixed guidebeam and in-guideway switching. The on-board concept has all active switch components mounted aboard the vehicle while the in-guideway concept relies on switches in the guideway. The operating concept of the proposed system including the frequency of switching is one of the key factors in the evaluation.

The proposed system utilizes switches only for reversing directions at the ends of the line, and for rare emergency cross-overs to bypass a guideway section under repair. If the Airport-Waikiki transfer service is ultimately implemented, switches would be required between the main line and the Airport spur link; similarly, a new line branching off the main line would also require switches. In any case, the number of switching operations necessary for transit operations is relatively small. (It has been estimated that the switches at the ends of the lines would operate 360 times a day.)

Since each of the terminus switches must move twice, once after the train reaches the turn back trunk and again after the train has cleared the switch into the station, so that the next train can be received, each complete circuit of each train requires four actuations of a switch. Since there are some 38 non-terminus switches on the guideway, and the train must pass through the terminus switches twice on each circuit, for the 360 daily train circuits there will be 1,440 switch member activations and 13,680 switch passes.

In contrast, an on-board switching mechanism would require many more daily actuations than the guideway switch system. Most on-board systems utilize fixed or passive guideways (although the LTV Airtrans system does have a moving guideway element, which would have to be activated the same number of times as a guideway switch). At each switch point, the on-board switching mechanism on each vehicle must engage an element of the guideway on one side or the other, to direct the vehicle in the desired direction. For the 2,300

vehicle round trips daily (equivalent to the 360 trains round trips discussed above), 9,200 switch arm actuations and 174,800 switch engagements would be made, many more than would be necessary with in-guideway switching.

In a system with many switch points, such as a PRT network with many off-line station or a complicated people-mover network, there may be an advantage in utilizing on-vehicle switching and passive guideways. However, in systems with many vehicles operating in trains and very few switch points, it has been found advantageous to utilize in-guideway switching, from a system reliability standpoint as well as from a cost standpoint. While on-board switching can allow higher speeds, at least through the turn-out position, because much greater radii of curvature are feasible, the switches on the proposed system do not require high speeds. On-board switch mechanisms would have to be individually checked by an automatic train control system prior to the train's entering each switch, a much more complex process than that necessary to check the in-guideway switch in front of each train. At the present time, there is no proven system utilizing on-board switching system for trained-vehicle operation as proposed for Honolulu.

As was mentioned above, on-board vehicle switching concept is considered to be more applicable to systems requiring frequent, high-speed switching. For a conventional trunk line system utilizing the transit mode of operation, the actual switching operation is infrequent and can be done at a relatively low speed. Therefore, an in-guideway switching mechanism utilizing available state-of-the-art and proven train protection system would provide a more reliable system.

COMPARISON OF GUIDANCE SYSTEMS

The original decision on vehicle technology was based primarily on the results of the Transit Expressway test experience. Guidance for that system was via a center guidebeam. However, many of the rubber-tired transit vehicles developed recently have featured outboard guidance systems, so an analysis was undertaken to determine if outboard guidance possessed any significant advantages over the recommended central guidance.

The findings of the survey were somewhat inconclusive. Designers of transit systems were unable to identify any clear-cut advantages for either center or outboard guidance; in fact, manufacturers of outboard guidance systems indicated that they would consider center guidance

for future designs, and manufacturers of center guidance systems were equally indecisive.

Center guidance does have a clear-cut advantage in operational experience on systems utilizing non-rail switching; the Sapporo Metro system has been operating since 1971, and the Transit Expressway demonstration project underwent extensive, thorough testing. In addition, most of the smaller people-mover systems, such as the many Rohr systems installed at amusement parks, use a form of central guidance. In contrast, the LTV Airtrans at Dallas-Fort Worth Airport went into operation only in 1974, and the Boeing Morgantown PRT will not go into operation until 1975.

The Airtrans installation presents an example of one of the inherent problems with outboard guidance systems - the difficulty in properly aligning two parallel sidewalls relative to each other as well as to the way structure and roadway. The Airtrans guideway was not constructed within specified tolerance limits, and the lateral ride quality of the airtrans vehicle suffers because of the minor irregularities in alignment. A single center guidebeam is inherently simpler to align properly, although Westinghouse has experienced some difficulties in matching the ends of the steel I-beams on curved guideway segments. (The Boeing guidance systems avoids this pitfall of outboard guidance by bearing against only one of the sidewalls, but the steering bias of the support wheels used to maintain the vehicle's position relative to the sidewall results in excessive tire wear.)

Another possible advantage for center guidance is that the guideway cross section is inherently smaller, both in width and depth, at least where the guideway is elevated. For vehicles with equal track width, the outboard guidance guideway must be wider to accommodate the side guidewheels and the guidewalls; the height of the guidewalls is greater than the additional depth needed to accommodate the center guidebeam. However, this apparent advantage for center guidance is alleviated when noise suppression is considered, because sidewall shields will be required to meet legal noise level limits.^{4/}

In guideway switching, mechanisms are comparable for center and outboard guidance (side guidance is advantageous for on-vehicle switching). Perhaps the simplest type of switch for center guidance is the Lateral Rotation (LR) type, in which the alternate tangent and turn-out guidebeams are pivoted at the diverge end of the switch.^{5/} Westinghouse has conducted extensive operating tests of this type of switch, although it has not yet been installed on a test track to be used by vehicles. Slightly more complicated switches involve lateral

translation (LT) of two of the alternative center guidebeams or vertical translation (VT) of the alternative guidebeams; these concepts have been successfully applied at the Transit Expressway test track (LT) and at the Sapporo Metro (VT). Both concepts are also applicable to outboard guidance, although with somewhat more complexity.

The central guidebeam switch, particularly the LR switch under development by Westinghouse, does have the significant advantage of allowing a much larger turn radius for the same switch length as comparable outboard guidance would be limited to a radius of only 50 feet. Speeds through the larger radius switch could be substantially higher.

In summary, the advantages of the center guidance over outboard guidance may be stated as follows:

- More operational experience
- Simpler to align a single guidebeam than two parallel beams
- Narrower guideway width
- Larger radius for similar length of switch
- Lateral movement only of switch as compared to both lateral and vertical movements required for the outboard guidance switch
- Simpler and smaller switching mechanism

Although distinct advantages can be shown for the center guidance system over the outboard guidance system, both concepts are considered to be feasible for application to a trunk line system. Specifically as related to the Honolulu system, one critical factor could be the greater guideway width required for the outboard guidance system as related to the segments of the transit route in existing freeways. Based on the vehicle system design, if the guideway width is somewhat greater than that required for the center guidance vehicle system, difficulties may be encountered in locating the system in the freeways as proposed.

Based on the results of this survey and evaluation, it is concluded that the initial recommendations are still valid, with some minor refinements, and that preliminary engineering should continue to be based on the center guidebeam concept. However, it should be recognized that the advantages are slight and that if any new developments should take place on the outboard guidance system in the near future, it should be carefully examined for possible application to the Honolulu system.

V. REFERENCES

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VI. APPENDICES

A. CRITERIA FOR RIDE QUALITY

The specification and assessment of vehicle ride quality characteristics are currently an art rather than a science. The wide disparity of experimental techniques, results, evaluations, and conclusions in the literature are amply portrayed in References 8 and 9. On the one hand, this body of analysis and experimental research provides little guidance in the selection of one set of criteria over another. On the other hand, operational systems provide such a wide range of ride quality that criteria must be selected upon which to base design and procurement of a system so that reasonably acceptable ride quality will be attained.

The resultant quality of ride has components of at least six degrees of freedom, i. e., translational in the longitudinal, lateral, and vertical axes; and rotational in the yaw, pitch, and roll modes. The complexity of the problem can be visualized by recognizing that ride quality is further affected by simultaneous combinations of these parameters, as well as their second derivatives (jerk rates).

From another point of view, ride quality disturbances can be divided into two categories, those of a vibratory nature and those of a random single incident nature. The writers found very little objection to the vibrational characteristics of the systems on which they were passengers, with the one exception of the previously discussed "bad spots" on the Mexico City Metro. On the other hand, their ratings of poor on several of the systems are due primarily to the random "single cycle" disturbances rather than the vibrational ones. Therefore, it is difficult to understand why most of the investigations appear to have dealt with the latter type.

Many proposed criteria for the vibrational category of ride quality are presented in References 8 and 9, and the many references contained therein. These criteria are usually expressed as a "Coefficient of Comfort" which defines a relationship between the maximum permissible disturbance along a given axis and the vibrational frequency of that disturbance for a given level of ride quality or "comfort". Typical of this approach are the criteria developed by the Japanese National Railway. These JNR criteria are shown on Figure VI-1. Curves are presented for coefficients of 1.0, 1.5, 2.0 and 3.0 for each of the three axes. Each curve represents the variable limit of disturbance magnitude over the frequency range to meet the specified coefficient of comfort. To place the coefficients in a framework of experience, the following table is presented.

<u>Coefficient Range</u>	<u>Rating</u>
< 1.0	Excellent
1 to 1.5	Very Good
1.5 to 2.0	Normal
2.0 to 3.0	Bad
> 3.0	Very Bad

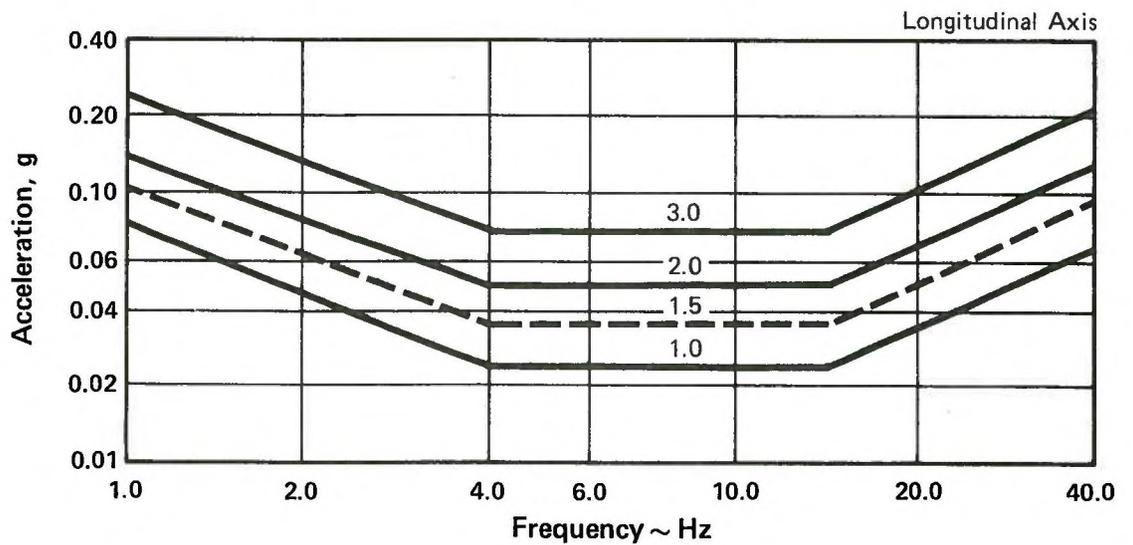
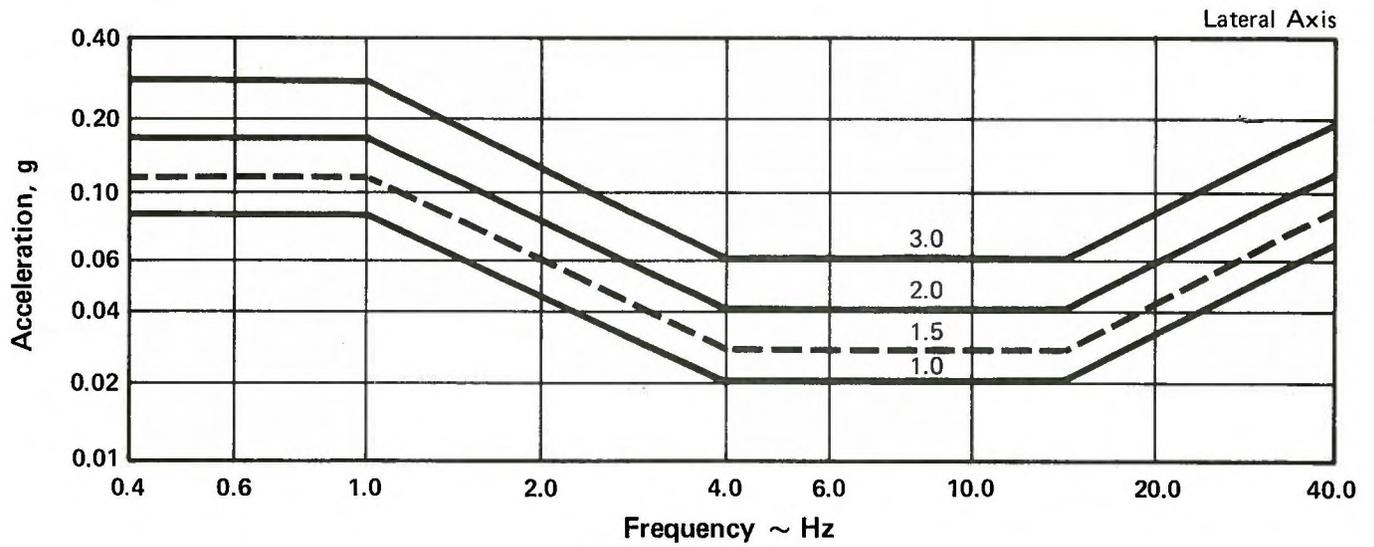
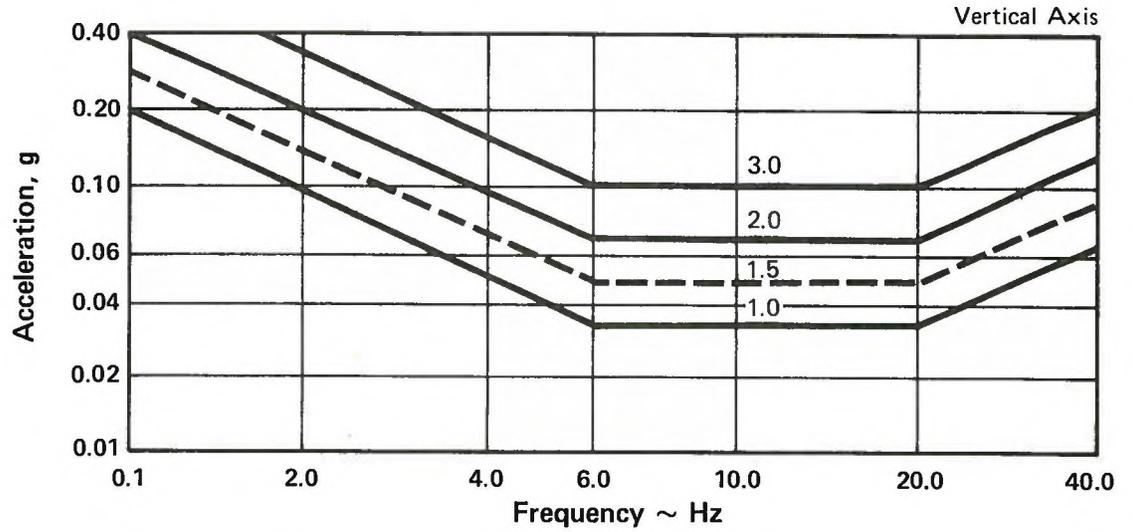
For further clarification, automobiles typically fall in the coefficient range of 1.0 to 1.5; the New Tokaido Line Bullet Train has a coefficient of 1.5, writing by a passenger is possible up to a coefficient of 2.0, and city buses usually fall in the range of 3.0 to 5.0. The coefficient of 1.5 (dashed curves on Figure VI-1) is considered the limit for ride comfort.

It should be noted that disturbance amplitudes are severely limited in the frequency range of about 4 to 15 hertz. This is the range of frequencies in which the natural resonance of the major human organs such as the heart, kidney, and liver occurs. Large disturbances in this frequency range are to be avoided, and vehicles should be designed so their resonant frequencies fall below this range. Allowable accelerations are highest in the vertical axis and lowest in the lateral axis; this agrees with the assessment of the writers - lateral disturbances were the most annoying and vertical ones the least annoying. Finally, for the lateral axis, no increase in disturbance amplitude is allowed below a frequency of 1 hertz. This is apparently an attempt to deal with the lateral, single incident disturbances which the writers found so annoying on several of the systems.

It would appear that the JNR criteria are as good as any and that the coefficient of comfort curves of 1.5 would yield a system with good ride quality without undue complexity. The single resultant vector type of criterion, as proposed by some, is not considered to be a satisfactory means of establishing ride quality. The JNR criteria should be expanded by inclusion of a random single event acceleration limit for each of the three axes. This single event acceleration limit should also define maximum permissible jerk limits for each axis.

FIGURE VI-1

COEFFICIENT OF COMFORT-JAPANESE NATIONAL RAILWAY



B. VEHICLE WEIGHT AND LENGTH

Several correlations of the gathered data were attempted for arriving at methods of predicting the physical characteristics of medium-capacity, rubber-tired transit vehicles for the purpose of preliminary design. Correlations for vehicle weight and length were established, which permit such prediction with sufficient accuracy for this purpose.

Since the available base data were for vehicles with a range of passenger complements from all seated to all standing, attempts were made to normalize the passenger load by developing an "equivalent number of passengers." A good approximation to passenger space requirements is that a standing passenger uses about one-half the floor area of a seated passenger. The equivalent number of passengers (N_{pe}) was defined then as:

$$N_{pe} = N_s + 0.5 N_{st} \quad (1)$$

where: N_s = No. of seated passengers

N_{st} = No. of standing passengers

The values of N_{pe} for the various systems, along with other physical characteristics of the various vehicles, are contained in Table VII-1.

Referring to Figure VI-1, the relationship of N_{pe} and empty weight (W_e) for the various vehicles is shown by the numbered, plotted points. The numbers correspond to system numbers as used throughout this Report. The heavy, solid line depicts an average variation of N_{pe} vs. W_e for the surveyed systems. The range of vehicle sizes of interest to medium-capacity systems (say, N_{pe} 's of 20 to 80) can be approximated by a straight line (not shown) of equation:

$$W_e = 390 N_{pe} + 2,700 \quad (2)$$

Equation 2, then, represents a correlation of the equivalent passenger loads and vehicle weights of a sizable group of medium-capacity, low-speed (up to 35 mph) transit vehicles. The degree of correlation is quite good considering the different companies, countries, sizes, purposes, design philosophies, etc., of these vehicles.

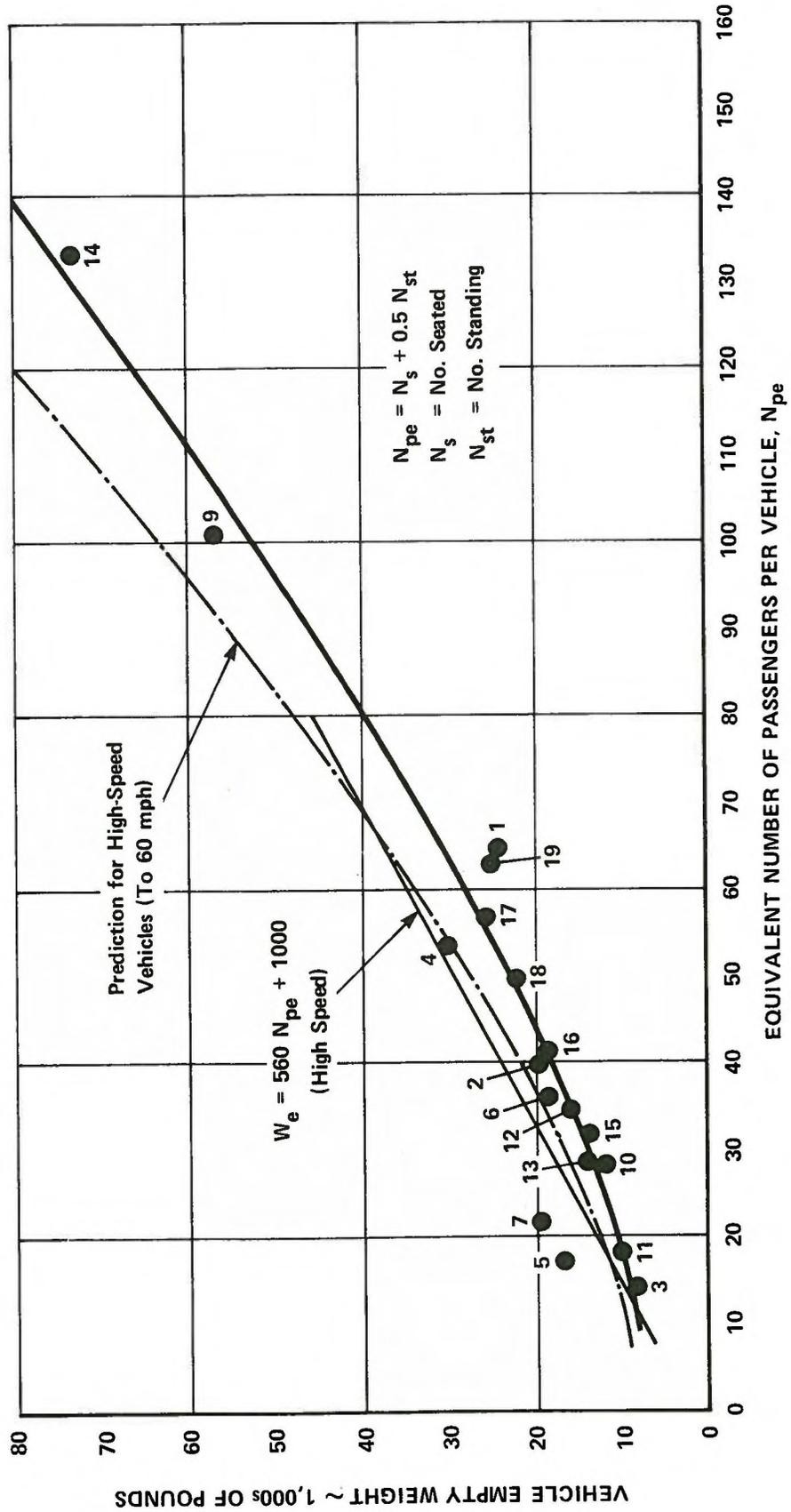
However, vehicles of interest to Honolulu would have considerably higher speed capability - perhaps up to 60 mph. These would require higher installed power, more sophisticated suspension, higher quality, and probably larger tires, etc. To allow for such upgrading, the weight correlation based on the survey vehicles has been raised by 20 percent, as shown by the upper, dashed curve on Figure VI-1. The applicable passenger load

TABLE VI-1
VEHICLE SIZE AND WEIGHT CHARACTERISTICS

SYSTEM	MODEL	DIMENSIONS			NO. OF PASSENGERS			WEIGHT (lbs)		$K = \frac{N_s}{N_t} \sim 0.5 N_{st}$	EQUIVALENT PASSENGERS ($0.5 N_{st} + N_s$)	UNIT LENGTH WEIGHT ^a (lbs/ft)	UNIT AREA WEIGHT ^a (lbs/sq ft)	UNIT LENGTH (ft/pass.)	UNIT AREA (sq ft/pass.)
		L (ft)	W (ft)	A (sq ft)	Seated	Standing	Total	Empty	Gross						
1. BENDIX DASHAVEYOR	Transpo '72	42.0	9.0	378	40	50	90	24,000	37,500	0.44	25.0	571	63.5	0.47	4.20
2. BENDIX DASHAVEYOR	Animal Domain	28.0	7.3	210	40	0	40	19,200	25,200	1.0	0	686	91.4	0.70	5.25
3. BOEING	Morgantown	15.5	6.7	104	8	13	21	8,750	11,900	0.38	6.5	565	84.1	0.74	4.95
4. FORD ACT	El Paso/Juarez	42.0	8.7	365	36	36	72	30,000	40,800	0.50	18.0	714	82.2	0.58	5.07
5. FORD ACT	Fairlane	24.8	6.7	166	10	14	24	16,800	20,400	0.42	7.0	677	101.2	1.03	6.91
6. KAWASAKI	KCV-12	29.8	7.7	229	24	26	50	18,772	26,272	0.48	13.0	630	82.0	0.60	4.58
7. KAWASAKI	KCV-13	20.8	7.7	160	14	16	30	9,912	14,412	0.47	8.0	477	62.0	0.69	5.33
8. LTV	Airtrans	21.0	7.0	147	16	24	40	14,000	20,000	0.40	12.0	667	95.2	0.53	3.68
9. MEXICO CITY	Metro	56.3	8.2	462	40	126	166	56,891	80,229	0.24	63.0	1,011	123.2	0.34	2.78
10. MITSUBISHI	MAT	18.7	7.2	135	16	24	40	13,216	19,216	0.40	12.0	707	97.9	0.47	3.38
11. JAPAN ROLLING STOCK COMPANY	VONA	19.7	6.6	130	11	14	25	10,080	13,380	0.44	7.0	512	77.5	0.79	5.20
12. NIIGATA ENG. CO.	Newtran	23.3	7.5	175	20	30	50	15,680	23,180	0.40	15.0	673	89.6	0.47	3.50
13. ROHR CORP.	DMV	26.1	8.0	209	21	15	36	14,500	19,900	0.58	7.5	556	69.4	0.73	5.81
14. SAPPORO	Metro	88.6	10.1	895	82	104	186	73,024	100,924	0.44	52.0	824	81.6	0.48	4.81
15. TOKYU CAR CO.	PARATRAN	23.8	7.2	171	24	16	40	13,440	19,440	0.60	8.0	565	78.6	0.60	4.28
16. WESTINGHOUSE	Transit Expressway	30.5	8.7	365	28	26	54	19,500	27,600	0.52	13.0	639	53.4	0.56	6.76
17. WESTINGHOUSE	SeaTac	37.0	9.3	344	12	90	102	25,500	40,800	0.12	45.0	689	74.1	0.36	3.37
18. WESTINGHOUSE	Tampa	36.3	9.3	338	0	100	100	21,500	36,500	0	50.0	592	63.6	0.36	3.38
19. WESTINGHOUSE	Miami	38.0	9.0	342	0	128	128	30,000	49,200	0	64.0	789	87.7	0.30	2.67

^aBased on empty weight.

FIGURE VI-2
VEHICLE WEIGHT EMPTY
versus
EQUIVALENT NUMBER OF PASSENGERS



range for this higher speed correlation can be expressed by the linear approximately:

$$W_e = 560 N_{pe} + 1,000 \quad (3)$$

For convenience of use, and to illustrate the effect of seated and standing passengers, Equation 3 was restated by introducing the factor:

$$K = \frac{N_s}{N_t} \quad (4)$$

The factor K, then, is merely the ratio of seated passengers (N_s) to total passengers (N_t). It is possible, by this means, to derive an equation for N_{pe} in terms of K and N_t as follows:

$$N_{pe} = \left[1 + \left(\frac{1-K}{2K} \right) \right] KN_t \quad (5)$$

Substituting Equation 5 into Equation 3, the expression for vehicle weight in terms of standing passenger ratio and total passenger load can be derived as:

$$W_e = 56 \left[1 + \left(\frac{1-K}{2K} \right) \right] KN_t + 1,000 \quad (6)$$

or: $W_e = 560 f(K) N_t + 1,000 \quad (7)$

where: $f(K) = \left[1 + \left(\frac{1-K}{2K} \right) \right] K \quad (8)$

The function $f(K)$ is simply calculated between its limits of zero and unity as follows:

<u>K</u>	<u>f(K)</u>	<u>Comment</u>
0.0	0.5	All standing
0.2	0.6	
0.4	0.7	
0.6	0.8	
0.8	0.9	
1.0	1.0	All seated

The variation of vehicle weight empty with total number of passengers and ratio of seated to standing passengers resulting from Equation 7 is shown on Figure VI-2.

A process similar to that just described was used to obtain a predictive correlation of vehicle length. Vehicle length (L_v) for each system surveyed as related to vehicle N_{pe} is shown by a numbered, plotted point on Figure VI-3. Based on these points, the average line is expressed by the equation.

$$L_v = 0.58 N_{pe} + 6.3 \quad (9)$$

As in the case of vehicle weight, Equation 9 can be derived into the form:

$$L_v = 0.58 f(K) N_t + 6.3 \quad (10)$$

The resulting vehicle length correlation is shown on Figure VII-4.

The factor of vehicle empty weight per unit length (W_e/L_v) is also of considerable interest. The data from Figures VI-2 and VI-4 have been used to develop such a correlation. The result is shown on Figure VII-5. This figure illustrates the inappropriateness of using a single value of weight per unit length in predicting vehicle weight.

The correlations presented on Figures VI-2, VI-4, and VI-5 should be very useful during the preliminary design phase of medium-capacity, rubber-tired transit systems as input to preliminary structural analysis and trade studies of vehicle size vs. train consist. The data presented in Table VI-1 can provide insight into other physical parameters useful to design activity.

FIGURE VI-3
PREDICTED EMPTY VEHICLE WEIGHTS
FOR HIGH SPEED,* MEDIUM-CAPACITY SYSTEMS

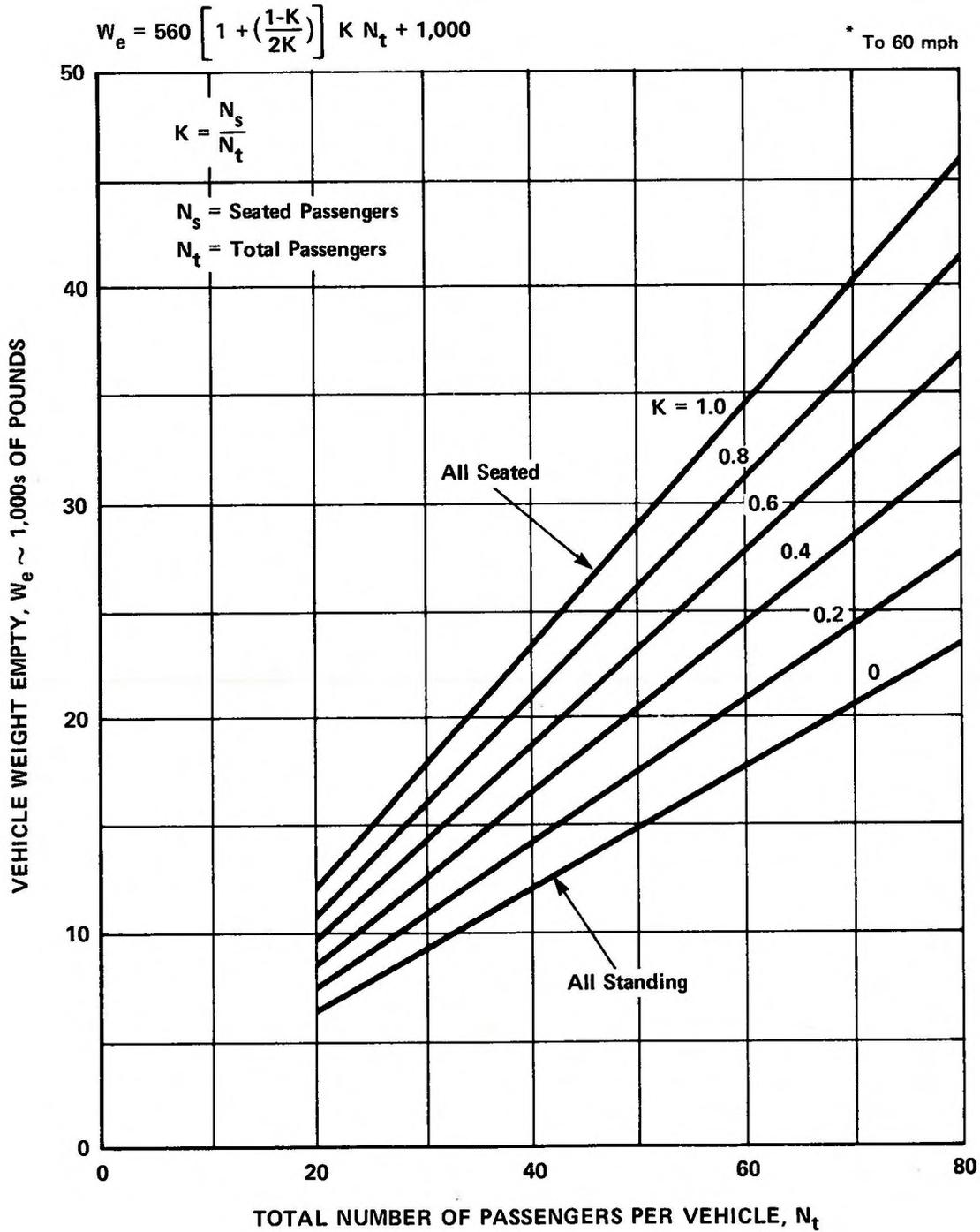


FIGURE VI-4
VEHICLE LENGTH
versus
EQUIVALENT NUMBER OF PASSENGERS

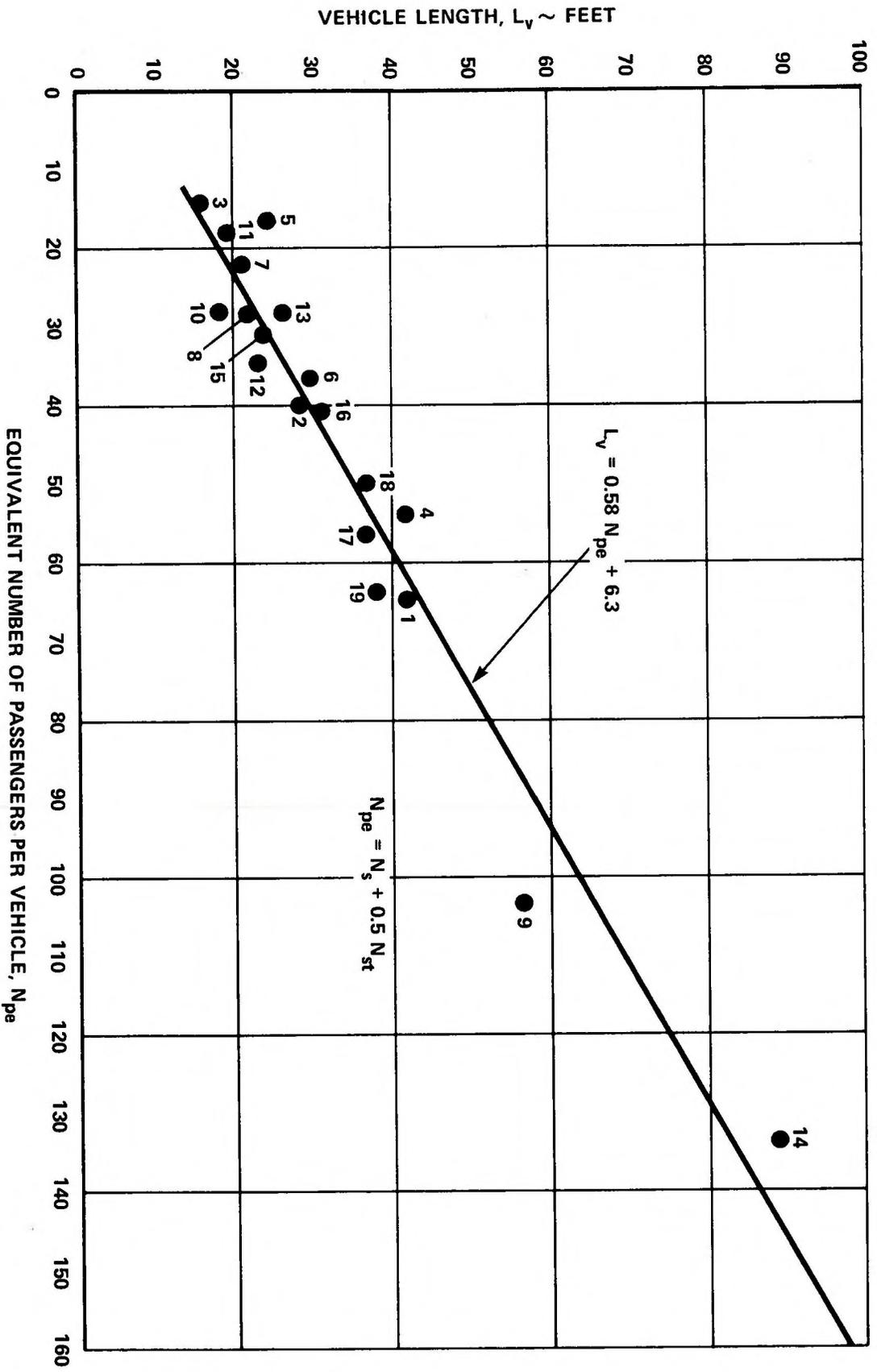


FIGURE VI-5
PREDICTED VEHICLE LENGTHS

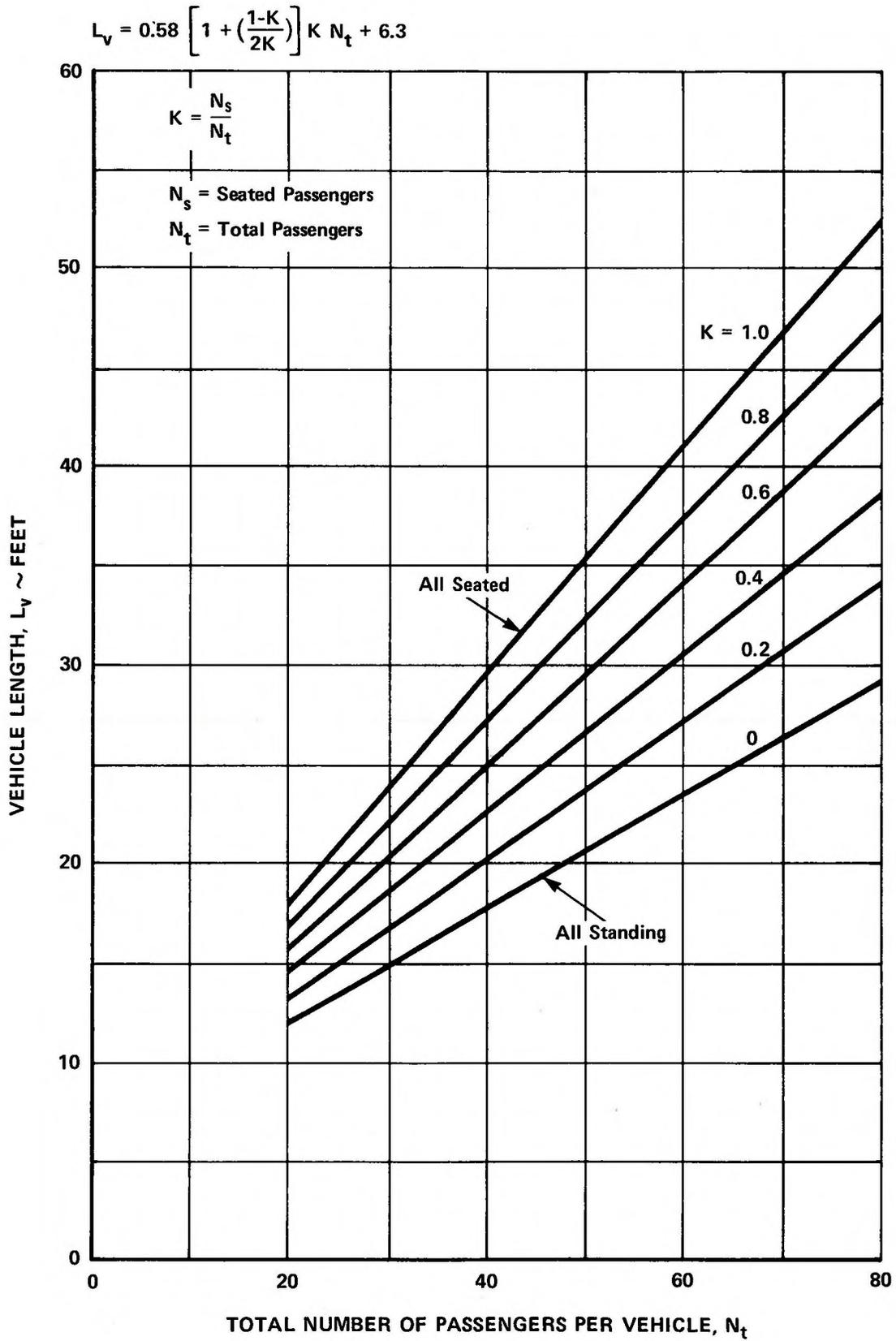


FIGURE VI-6
VEHICLE WEIGHT EMPTY PER FOOT OF LENGTH

