"Monorail Technology Study"

TASK I: A Review of Monorail Systems

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PREFACE

This report summarizes the current "state-of-the-art" of monorail systems, their characteristics, capabilities and functional usage in urban transit. This information was developed for the Texas State Department of Highways and Public Transportation to familiarize the department with this technology and its applicability to urban corridors in some of the larger Texas municipalities.

Early in this endeavor it was realized that the traditional literature searches and document review would not produce the necessary information. Very little information has been published in professional journals concerning monorails and what has been published is either out of date or unsuitable. As a consequence, the majority of information collected came from organizations which are currently operating or building monorail systems. While this is without doubt the most current information it is not in public domain and not without bias.

Perhaps because of the lack of a firm base in the transportation literature there has been an accumulation of misinformation concerning the monorails and their uses. Myths have been perpetuated based on previous exposure to the technology in fair or amusement park settings or as the result of descriptions and appraisals of some of the earlier systems which have led transit and public decision makers to dismiss monorails without the consideration they may warrant.

It is the intent of this report to serve as a primer to the current technology which, it is hoped, will dispel some of the myths.

The second task of this project is to make a general comparison of operational characteristics and costs among monorail, conventional rail, light rail and other forms of mass transportation suitable for use in urban areas. The last task is to determine the applicability of monorail technology to various urban corridors in selected Texas citites.

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INTRODUCTION

In 1960, Hermann Botzow published his masters thesis on monorails in book form. In the foreword to the book, A. S. Lang, Botzow's academic advisor, wrote; "It is surely no secret that the problems of transporting people and goods in and around our cities have assumed major proportions. The time has long since passed when we should have marshalled all our technological capabilities in search of workable solutions to them. Yet the field of transportation engineering suffers from a singular lack of unity and central purpose. There has been little attempt made, for instance, to assess soberly the characteristics of our available transportation media and to compare them on their basic merits. It seems that partly as a result of this neglect we are not solving our problems as quickly as we should.

"Among the forms of transportation thought appropriate to the urban environment, monorail is both the most loudly hailed and the least well understood. It has been promoted to the point that it has its wild enthusiasts; yet no one has seen a monorail transit system in actual operation. The fact is that we have little reliable information on the subject, because no one has yet taken a look, which attempted to be at once objective and relatively complete." (1)

A good portion of this statement is still true some twenty years after it was written. While there have been attempts at solving urban transportation problems using new and innovative approaches they have generally focused on making more efficient use of the existing highway system. These approaches include the dedication of special use lanes for high occupancy vehicles (HOV) or reverse traffic flow. There have also been attempts to compare transit modes on their merits. However, in the United States the application of monorail technology to transit systems appears to have been frozen in time. The technology itself has been advanced and applied in the urban mass transit mode in other countries but transit authorities in the U.S. still respond as if it is an unproven system with little reliable information available.

Perhaps this is due to the difficulty in obtaining information or the casual observation that monorail systems have been limited to the circulation of tourists and have no place in a transit system.

The information exists, but it is difficult to acquire because it is generally anecdotal and must be obtained first hand. The characteristics of the foreign transit systems that have been built using monorails, are not directly applicable because of geographical, cultural and, in some cases, physical differences of the ridership population. However, the structures, performance characteristics and operations can serve as models of the technology.

The most valuable contribution this report can make is to bring the attention of the reader the changes that have taken place in monorail technology and to correct some of the erroneous notions that have grown up for the last twenty years.

MONORAIL DESCRIPTION

As can be surmised from the word itself "monorail" means "single rail". It is one of those generic terms that covers a variety of systems and is apt to lead to miscommunication. It will conjure different mental images depending on the experience of the individual using it and the context of the conversation.

Perhaps the most prevalent monorail system in use today is the overhead crane type that can be found in large industrial complexes over the globe. These, of course, are not the subject of interest because they are not generally used to transport passengers. Historically, however, the passenger variety of monorail systems had their humble beginnings as cargo carriers.

The interest here is in the passenger carrying monorails. Again there are various types of these systems. They can be categorized according to structure, and the method of propulsion.

A good description of the subject systems is required (if the pun can be forgiven) to get everyone started on the right track. This includes a sound working definition, a classification of the types of systems, and a brief history.

DEFINITION

Monorail is a term applied to various types of passenger and cargo vehicles that travel on a single track or beam. Since the current discussion is concerned with transportation of passengers in urban areas, this definition can be amended for that context.

Urban monorails are those vehicles that travel on a single rail or beam that can be used to carry passengers in urban areas.

It should be noted that this definition includes some systems that are not currently being used for urban transit.

TYPES

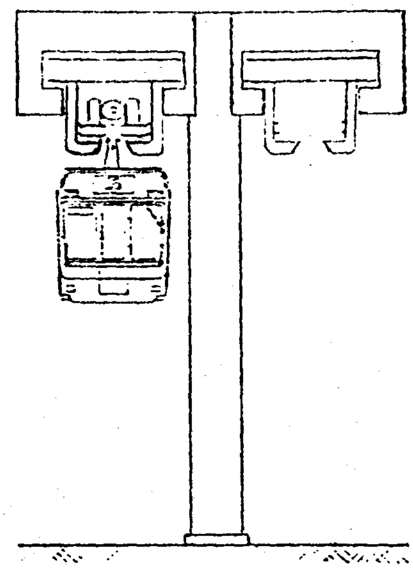
Monorail systems that currently satisfy the definition can be classified according to their structure and their method of propulsion.

Most monorail systems have elevated rail support structures which allows the vehicles to either be suspended from the rail or supported by it. As the name implies, the suspended system mounts the vehicle directly below the rail member. The metal rail is usually a rectangularly shaped, split bottom, box beam girder. The vehicle is attached by suspending the vehicle directly below bogie or truck assemblies which are contained in the rail beam. The drive wheels or traction tires run along the lower flanges of the girder. The system shown in Figure I-A represents the symetrical type of suspended system.

An asymmetrical design has been used where the load of the vehicles is transmitted to the traction wheels by means of a lateral arm attached to the top of the vehicle. This arm then curves around the rail support and attaches to the bogie containing the drive wheels. This is the design of one of the oldest monorail systems, however, it has not been used in recent years. (1,2)

In the supported system the vehicle straddled a concrete or steel running rail. The rail is wide enough to permit the drive wheels to run on top and

A. Suspended



B. Supported

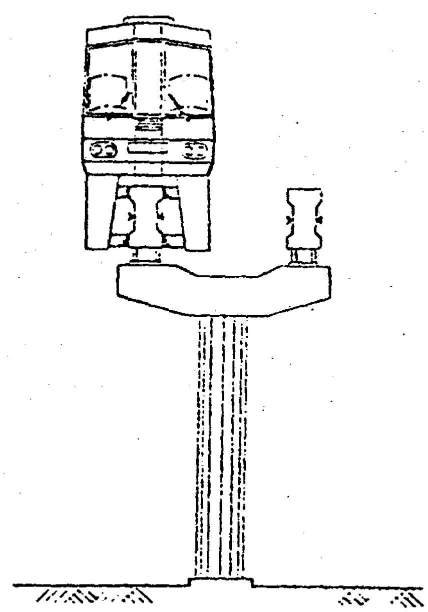


Figure 1. Monorail Structures

Source: Japanese Monorail Association Brochure (2) deep enough to allow support wheels to be mounted on either side to maintain lateral stability (see Figure I-B). This arrangement creates the impression that the vehicle is almost wrapped around the rail.

Most supported systems are variations of the Alweg design. This design was developed by a Swiss industrialist named Alex Wenner-Gren in collaboration with the Krupp Corporation of West Germany. (1,2,3)

The propulsion systems that have been used for monorail systems include: gasoline engines, electric motors, cable drive and magnetic levitation. Of these, by far the most prevalent has been the use of electric motors. A few demonstration systems using gasoline engines were built in the 1950's and 60's but they were discontinued. Cable drive systems are being used to propell vehicles where the distance travelled is short and trips can be from point to point with few stops in between. Magnetic levitation is a relatively new technology in which magnetic forces are used to both lift the vehicle and propell it. Current designs use a single rail for these systems, however, they are proposed for use in an interurban network because of the high speed they are able to acheive. Maglev systems have attained speeds in excess of 250 mph. (4)

When considering the system most likely to be found in use as urban transport, it would use electric motors for propulsion and be of the suspended or supported type. These systems represent existing, state-of-the-art technology requiring no research and development for implementation. The other systems mentioned either have restricted uses or are pushing the state-of-the-art in terms of technological development. Consequently, the focus of this report will be on the electric systems of either the suspended or supported variety.

HISTORY

Monorails have been in use since 1821 when an Englishman built a horse drawn system for transporting materials in a London navy yard. This monorail and another one like it were built by Henry Palmer using board rails supported at intervals by poles.

The first passenger monorail was built in 1876 for the Philadelphia Centennial Exposition. In 1890, a commercial line was developed connecting Brooklyn and Coney Island. During this same period several other cargo and passenger monorail lines were established in California and Ireland.

In 1901, a suspended type passenger system was constructed in Wuppertal, Germany. This system is still in operation carrying over 16 million passengers annually.

Ostensibly, the cargo monorails were developed either to conserve space and reduce transportation costs. The passenger monorails were built for their cost savings but also for their novelty and to provide a scenic vantage platform. Undoubtably, part of the motivation for building these systems rested in the engineering challenge they presented and the sheer love of the concept. This motivation was necessary to sustain the monorail enthusiasts during the automobile and highway expansion period following World War II.

In the late 1950's there was a resurgence of interest in "new" technology which was created by the prosperous economic conditions and the "Sputnick" challenge in space. This led to repeated demonstrations of Space-age monorail systems in Houston and Dallas, Texas, Disneyland in California, and in

Cologne, Germany. With the exception of the Disneyland system, these prototypes were removed or were abandoned after a short period. The Disneyland system has been continuously upgraded and improved. It is still in operation.

The demonstration of monorail technology continued in the 1960's with installations at the Seattle World's Fair, the Tokyo Zoo, Hemisfair in San Antonio, Texas and many other areas. For the most part these systems were intended to circulate tourist around fair grounds and amusement centers. Once the attractions were over, the lines were usually discontinued. (1,3)

In the 1970's monorail systems began to be considered again as a means of transporting passengers in a transit rather than a tourist mode. This has occurred primarily in Japan.

In the United States monorails have been considered in general as part of the Federally required alternative evaluation process conducted prior to implementing a new transit system. However, these comparisons have generally dismissed monorails as unproven technologies. Consequently they have not been considered elegible for federal funding support, and not included in the detailed evaluation.

SYSTEM CHARACTERISTICS

Monorails, like most other transit systems, have three major components; vehicles, track and stations. Vehicles, generally referred to as rolling stock, include propulsion and propulsion with passenger units. The track in this case is the elevated structure used to carry the rolling stock. The stations, of course are the platforms used for loading or unloading passengers.

ROLLING STOCK

The major difference between monorails vehicles and traditional railroad vehicles is that the propulsion units on monorails are included in each car. There is no locomotive per se. The lead vehicle in a train has a space for the operator, otherwise it is identical to the rest of the cars.

The size, weight and passenger carrying capacity varies with the type of system being used as does the vehicle performance. The range of passenger capacity is from 40 per car for the scaled down Alweg version used at Disneyworld where standing passengers are not allowed to 229 in the Japanese Hatachi-Alweg. The 229 passenger capacity is based on a crush condition allowing only one square foot for each passenger.

The propulsion units are usually 600 volt, direct current motors which are capable of propelling the vehicles in excess of 60 mph. The normal operating speed is in the 45 mph range.

A summary of the characteristics of the rolling stock is presented in Table 1 for four systems now in operation. It should be remembered that only the systems in Germany and Japan are being used in a transit mode.

Table 1. Rolling Stock Characteristics

System	Wuppertal, Germany	Tokyo, Japan	Seattle, Washington	Disneyland Florida
Type	Suspended (MAN)	Supported (Hatachi-Alweg)	Supported (Alweg)	Supported (Modified Alweg)
Vehicle Description				
Empty Weight (lbs.)	48,896	55,000	25,000	18,400
Gross Weight (lbs.)	79,380	87,780	40,000	24,520
Normal Passenger Space:				
Seated	48	56	61	40
Standing	98	143	82	No Standing
Area (ft.^{2})	2.26	1.21	UKN	UKN
Crush Passenger Space:				
Seated	48	56	61	40
Standing	156	173	UKN	No Standing
Area (ft.^{2})	1.35	1.0	UKN	UKN
Vehicle/Train	2	4-8	4	5-6
Vehicle Performance				
Max Capacity(psgr/hr)	3,672	62,000	10,000	10,000
Min Headway(sec)	UKN	90	Single Trains	90
Cruise Velocity(mph)	16-17	45	45	40
Max Velocity(mph)	37.3	50-70	60+	60+
Max Grade (%)	+3	10	UKN	6
Propulsion				
Motor per car	2	4	2	1-2
Motor Placement	1/Bogie	all axles	1/Bogie	Bogie
Power Type	600 VDC	750-1500VDC	600 VDC	600 VDC
Switching				
Type	UKN	Flexible Beam	No Switching	Beam Replacement
Time (sec)	UKN	8-10	No Switching	30

STRUCTURAL COMPONENTS

As with all structures, the monorail structural system is composed of several components: the guideway, the pier supports, and the foundation.

The guideway is the most essential and unique aspect of the monorail system. The ideal guideway would be of uniform dimensions, which dimensions should be toward practical minimums, provide for complete housing of and access to all basic system support hardware, be visually attractive and acceptable, and be structurally sound and economically realistic. This is, obviously, a tall order for any structural component. Trade-offs and concessions must be made, but no compromise may be made on structural capacity and provision for support hardware. This leaves aesthetics, economics, and possibly some peripheral functions as negotiable features.

There have been several guideway structural configurations developed for each type of monorail system. In the case of the supported monorail the most common configuration is a hollow reinforced or prestressed concrete I-beam. (Figure 2A) This allows the drive wheels to run along the top surface of the beam and the stability wheels to run along the side of the beam. In the Alweg system, for a 100 ft. span, a beam 3 ft. wide and 5 ft. deep is required. In the majority of construction cases, precast prestressed beams are used for straight and large radius curved sections while reinforced concrete is used on the remaining curved sections.

Suspended monorails usually use steel guideway when supported asymmetrically and concrete or steel with steel or wood running surfaces, guideways when supported symmetrically. Modern Assymetric supported monorails have

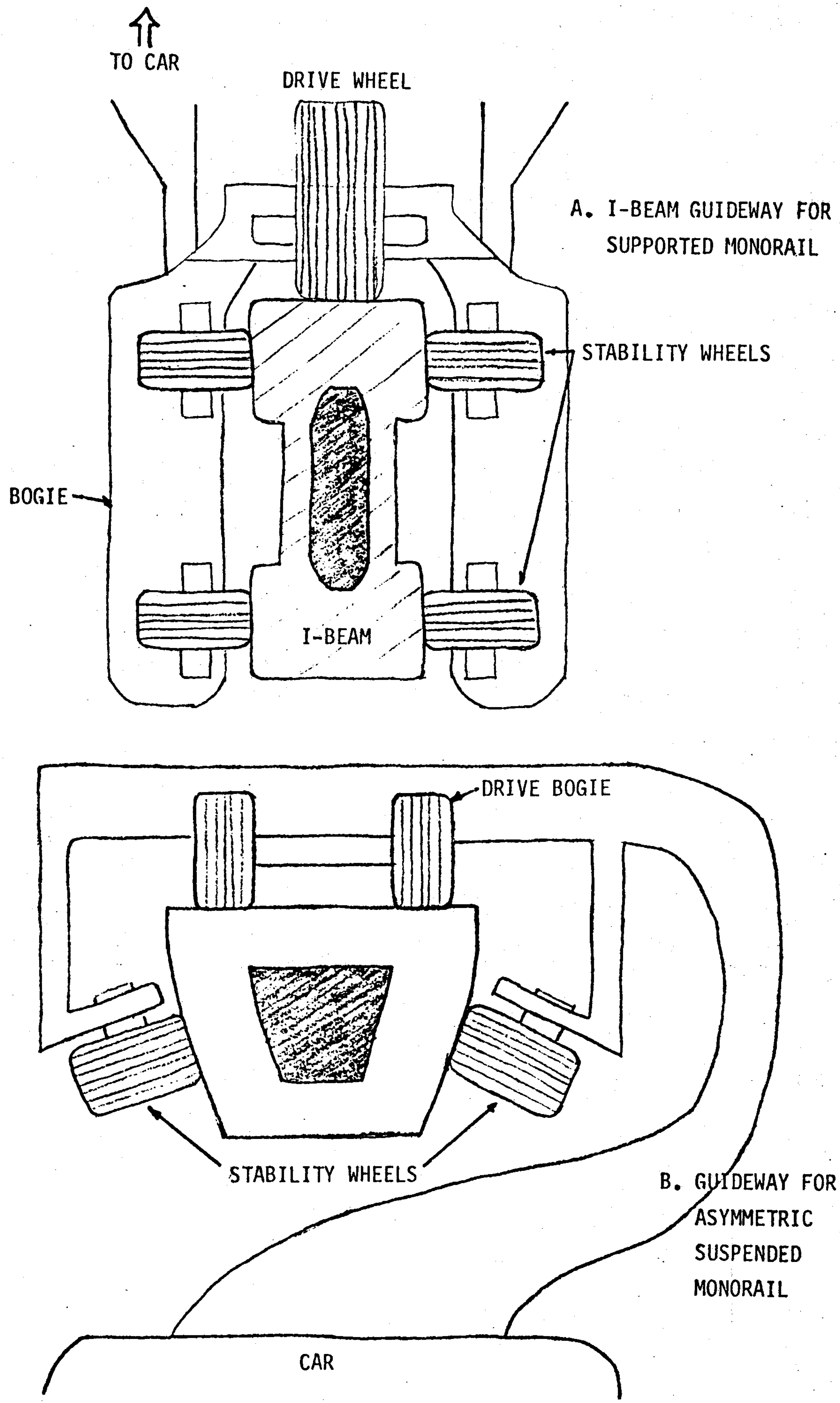


Figure 2. GUIDEWAY DESIGNS

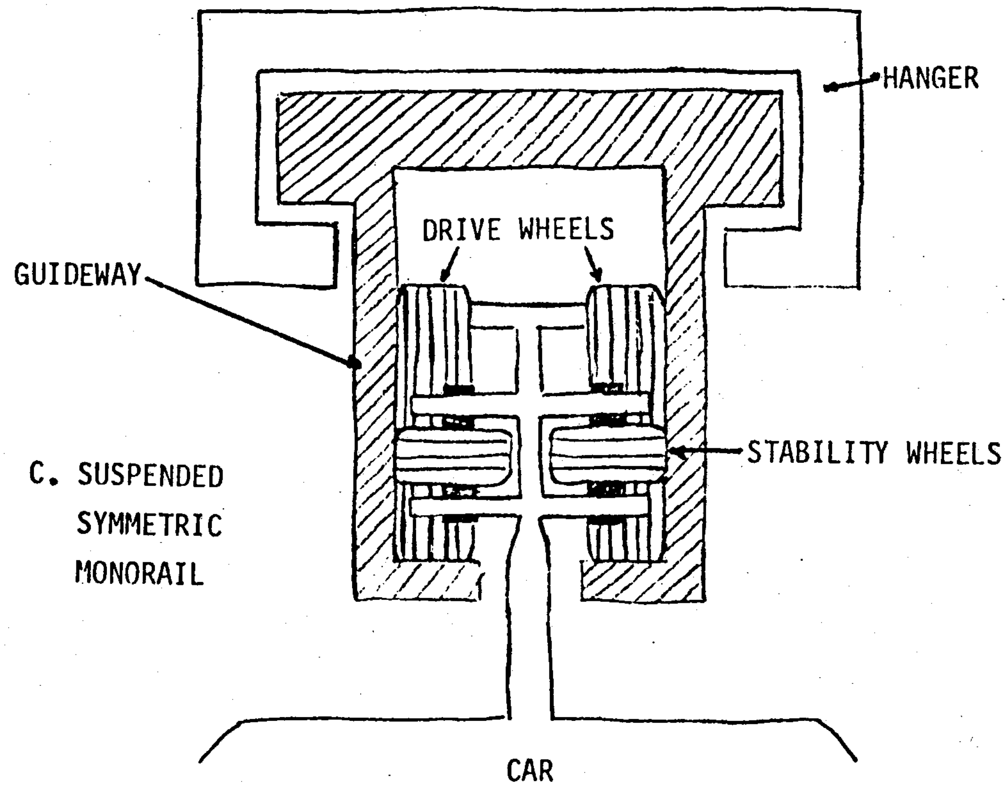


Figure 2 (Cont'd) GUIDEWAY DESIGNS

a triangular shaped steel rail which allows the drive wheels to run along the flat top surface of the rail and the stability wheels to run along either side of the sloping side surfaces as shown in Figure 2B. The symmetric supported monorails have a split-bottom box girder made of prestressed concrete or steel plate with a wooden or steel plate running surface on the inside of the lower flanges. The box girder must be large enough to allow the bogie or truck to ride inside the girder. See cross section of this design in Figure 2C.

There are really only three basic types of pier supports; T-shaped support, inverted J-shaped support, and single column support. These are shown in Figure 3A, B, and C. If two-way traffic is desired the T-shaped pier support will economically support one rail at each end of the cross member. The inverted J-shaped pier support is used when only one-way suspended monorail traffic is desired. The single column support is used for one-way supported monorail traffic.

One pier support system which is currently under investigation is the use of a cable-stayed guideway a concept similar to a suspension bridge. This approach, which would require extremely tall supports, would only be feasible in open or suburban areas. This approach is also applicable to all three types of monorail systems and would allow space of up to 300 ft. for the guideway.

Placement of the supports is perhaps the single most important element in the structural evaluation of guideways types. The constraints and limitations on support placement in an urban environment are restrictive. First and most obvious, pier supports must be kept clear of intersecting streets, not only for vehicle clearance but for sight distance as well. This also applies to any driveways or building loading zones. Very often, utilities will dictate areas to be avoided, particularly justified. Another significant constraint

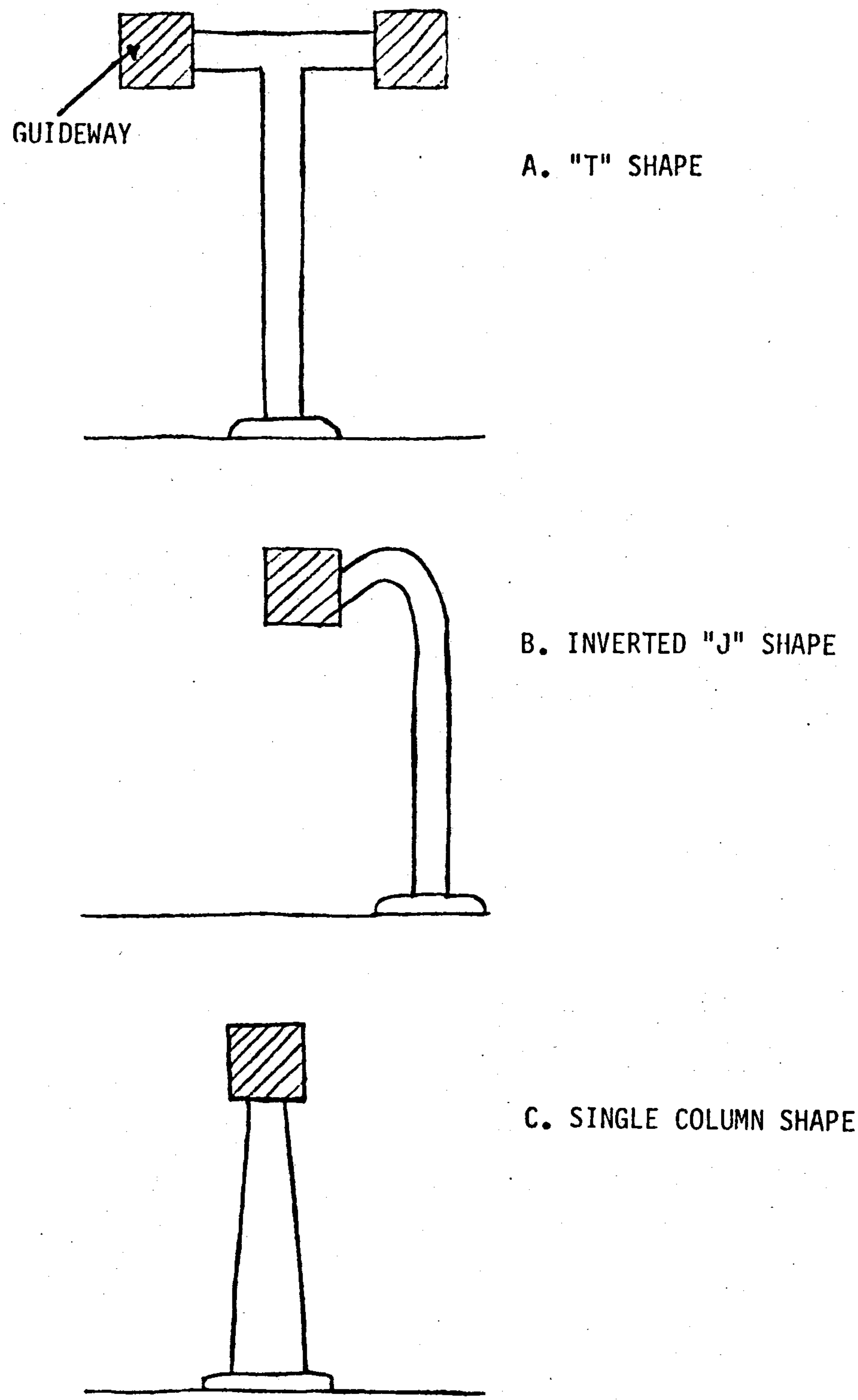


Figure 3. PIER SUPPORT DESIGNS

is support placement related to adjacent architecture. Both urban designers and building owners are sensitive to aesthetic integration of the structure with building features. These constraints, taken collectively, will usually dictate support placements that give wide variations in guideways span lengths. These constraints will also have an influence on the type of pier support best suited for the job and, furthermore, on the size and type of the guideway to be employed.

Any currently accepted form of foundation system can be made sufficient to meet the loading and peripheral requirements imposed by the system. In most cases the most critical loading on the foundations will be movement caused by the lateral wind load on the vehicle with respect to the pier support and the centrifugal force from the vehicle.

STATIONS

The elevated nature of most monorail systems dictates that loading platforms or stations also be elevated. When the system descends as is the case in the Disneyworld hotel, the stations can also be lowered. The station layout depends on the number of lines and desired loading points. There can be, for example, center loading stations between two tracks. There could also be three platforms, two outside and one center. Single line platforms can be located on either or both sides.

Station appointments could also vary with specified usage. As a minimum, they should include shelter from the elements for passengers, protection for fare collection mechanisms as well as queueing and safe boarding devices.

The major consideration concerning stations is the length of the boarding platform. It is the platform length that governs train length and thereby line carrying capacity.

MONORAILS IN SERVICE

A compilation of operational monorail systems, not associated with fairs nor intended for short term use, is presented in Table 2. This list was derived from various sources. It is reasonably comprehensive, but not exhaustive. It provides an idea of the numbers, types and usage of the technology. This Table also includes the Japanese monorails that are under construction as well as a list of those being planned. (1,2,3,5,6)

Although Table 2 summarizes the salient points for each system, additional information concerning these systems is presented in the following sections.

UNITED STATES

There are presently four major monorail systems in use in the United States; two located at Disney amusement centers, one recently constructed at Memphis, Tennessee and one operational at Seattle, Washington.

The monorail located in Disneyland in California is a down-scaled version of the Alweg supported design. It has two stations and is used to provide a senic tour of the park. The monorail system at the Disneyworld Park in Florida is longer but of similar design. It serves as the main link between the parking areas, hotel and park. Recently expanded, this system will provide transportation to an new attraction called the Epcot Center. Disneyworld's monorails presently carry over 25 million passengers a year and has a reliability record of 99.9% sustained over a ten year period. (5)

Table 2 Monorails Usage

Date Built	Location	Length (Miles)	Type	Use
		OPERATIONAL SYSTEMS		
1901	Wuppertal, West Germany	9.3	Suspended, Electric	Transit (18 stations)
1959/61	Disneyland, California	2.5	Supported, Electric	Tourist
1962	Seattle, Washington	1.1	Supported, Electric	Transit/ Tourist
1962	Inuyama, Japan	.86	Suspended, Electric	Unknown
1964	Tokyo, Japan	8.2	Suspended, Electric	Transit, (Airport)
1964	Yomuriland, Japan	1.9	Supported, Electric	Tourist
1971/82	Disneyworld, Florida	7.0	Supported, Electric	Transit/ Tourist
1980	Rhyl, North Wales	1.1	Supported, Electric	Tourist
1981	Memphis, Tennessee	.68	Suspended, Cable	Tourist
		UNDER CONSTRUCTION		
1983	Kitakyushu, Japan	5.2	Supported, Electric	Transit (12 stations)
1984	Osaka, Japan	8.3	Supported, Electric	Transit (9 stations)
1986	Chiba City, Japan	19.4	Supported, Electric	Transit (18 stations)
1987	Naha City, Okinawa	4.1	Supported, Electric	Transit (14 stations)
		PLANNED		
	Kawasaki, Japan	23.8		Transit
	Okayama, Japan	13.1		Transit
	Kumamoto, Japan	6.3		Transit
	Gifu, Japan	8.8		Transit

The cable powered, suspended system built in Memphis is used to shuttle tourist from the city proper to a recreational area at Mud Island. This unique system is suspended from the underside of a highway bridge crossing the Mississippi river. It has the capacity of carrying 3000 passengers each hour, making it the "highest capacity ropeway transportation system in the United States." (7)

The Seattle monorail was originally constructed for the World's Fair in 1962. It is a two station system designed to transport passengers from downtown parking to the fair grounds. Reportedly, the original capital cost of the system were recovered in the first five months of operation. Rather than remove the system it was donated to the Seattle Center which now operates the fair area as a cultural and amusement center. Currently, over 2 million passengers make the 1.2 mile trip each year. The 35 cent fare generates enough revenue to offset the operational cost. One cost savings aspect of the operation is the method of accelerating to 60 mph in the first quarter mile, then coasting the rest of the trip. This reduces the electricity usage while keeping the trip time down to around 90 seconds. (6,8)

EUROPE

Certainly, the Schwebebahn (swinging railroad) of Wuppertal, Germany illustrates the serviceability of monorail systems. This system, which has been operating continuously since 1901, carries over 16 million commuters annually. Botzow reported in 1960 that over one billion passengers had traveled the line at that time with a report of only two injured passengers.

One of the injuries resulted from the panic of a baby elephant which was being transported as a promotional stunt in 1952. He also points out that this low speed system (17 mph) was operating at a profit. (1,3)

Although there have been other demonstration systems built in Germany, France and Italy, they have been discontinued. However, recently a steel rail system has been completed in Rhyl, North Wales. This is the first public monorail to be built in the United Kingdom. It is a small, supported system designed to link the many attractions of the Rhyl resort area. It has a capacity of 1400 passengers per hour and relies on technologically simple and proven equipment. (9)

ASIA

Without doubt the greatest usage of monorail technology has taken place in Japan. Beginning in the early 1960's, the Japanese constructed several transit monorail systems. A suspended version was built in Inuyama to carry passengers from the main rail station to the seaside resort of Enoshina. A major line was created from Tokyo to the international airport at Haneda. This system had to be administratively reorganized when a new freeway route to the airport reduced its passenger demand. The reorganization and the rapid saturation of the freeway changed the situation so that the monorail line now enjoys a 14.4% share of the airport ridership. (2,10)

During the 1970 Exposition, in Osaka, an Alweg type monorail system carried 33.5 million passengers in six months. Although this was a tourist type system, its capabilities helped set the stage for subsequent monorail development.

The cause for the interest in monorail systems in Japan was created by a combination of dramatic increases in automobile traffic and the high costs associated with the construction of subway rail systems. In 1972, the Japanese parliament enacted legislation to promote urban monorail systems. This legislation included a mechanism allowing monorail track to be considered a special type of road and therefore eligible for interest free loans from public construction funds. Since the 1972 legislation,construction has begun on four systems and many others are in various stages of planning.

SYSTEM EVALUATION

All systems can be evaluated in both general and specific terms. General evaluations consider the advantages and disadvantages of a particular system without comparisons to other systems. Specific evaluations, on the other hand, attempt to be more quantitative by using other systems as a frame of reference. They are concerned with such things as the efficiency of a given system or its ability to produce desired results at the smallest cost.

To go further, specific evaluations may be equivalent or generic in nature. An equivalent evaluation attempts to compare the efficiency of systems with respect to some predefined requirements, or to compare systems designed for a specified operating environment. The generic evaluation attempts to compare salient aspects of representative examples of each systems with the realization that they are not equivalent. This type of evaluation,grounded on real-world examples, trades experience for rigor to provide a general idea of the rank order of efficiency of widely different systems. The generic type of evaluation was considered appropriate for this section.

GENERAL EVALUATION

The commonly stated advantages of monorail systems are that they:

1. Can be constructed quickly and simply
2. Have low construction costs
3. Are grade separated
4. Require minimal area at grade level
5. Have high ride comfort, little car sway

6. Are highly reliable

7. Are very safe

8. Cause little shading or visual obstruction

9. Produce little noise

The commonly stated disadvantages of monorail systems are that they:

1. Are a new and unproven technology

2. Have problems with switching

3. Provide no means of emergency egress

4. Are visually obtrusive and not aesthetically pleasing

The use of prefabricated concrete beams of great lengths (100-150 ft) allows monorail systems to be constructed quickly, with little disruption of traffic or commerce. The short construction period coupled with the simplicity of design produces a low cost of construction. If an elevated structure is required in any case, the monorail system, since it is much smaller than heavy rail elevated structures, affords the least obstruction of light and view for those who must live or work near the system. Elevated systems of any kind have long been known to be safe and reliable.

The electric propulsion and pneumatic tire design produces little noise and no pollution. The monorail vehicle is not subject to the rocking or swaying created in two tracked systems.

Since there are monorail systems currently being used elsewhere in the world the technology can hardly be considered unproven. The existence of operational systems being used in the U.S. in modes other than transit suggest that the technology is readily available and prototype systems would not have to be built.

Switching of monorail vehicles from one track to another is not the problem it has been. Flexible beams or beam replacement systems now allow switches to be made in less than 30 seconds, which is sufficient to accommodate train operating on 90 second headways.

Although slide chutes can be installed to permit egress from monorail vehicles in emergency situations, their safety and reliability records would not seem to warrant it. Slide chute operation without the presence of an attendent might pose a hazard, however the one operator on board might be able to oversee their deployment.

When aesthetics are considered, there is no doubt that an elevated structure placed in a collection of expensive office buildings or in residential neighborhoods would not be readily appreciated for its beauty. Experience in Seattle, Washington and around San Francisco Bay, has shown, however, that elevated systems come to be accepted in time whether monorail or heavy rail. Eventually, new structures are designed around the monorail system to provide a more pleasing and integrated archetecture.

SPECIFIC EVALUATION

The efficiency of a transit system is determined by some measure of its carrying capacity and the cost associated with generating that capacity. As far as capacity is concerned, the current systems in use demonstrated a capability of providing a wide range of capacities. Using variations in train lengths and spacing, a given monorail line can satisfy most demands placed on it. It should be pointed out that while some heavy rail systems are capable of servicing larger demands, they seldom operate at or near capacity. (Refer to Table 3). (11)

TABLE 3 Utilization of Major Urban Rail Systems

	World Wide Average	New York	Paris Metro	Moscow	Tokyo TRTA
Average Passenger Per Car	40.9	38.3	28.8	54.5	72.3
Car Capacity	185	350	164	170	144
Average Occupancy as % of Capacity	27.4	11.0	17.6	32.0	50.2

Source: (11)

The two major cost components of transit systems are the capital costs and operational costs (sometimes refered to as operation and maintenance or O&M costs). Obviously, capital costs depend on the length of the system, number of lines, pieces of rolling stock, right of way, stations, construction time, etc. But for a given system they are fixed. Operational costs, on the other hand, are variable. They vary with the level of service provided and to some extent the reliability and safety of the system.

Capital costs for monorail systems are lower than those for heavy rail systems constructed either above or below grade level. The construction cost of elevated structures for monorails is cheaper due to the lighter weight of the rolling stock and the relatively longer span distances involved. The cost of elevated monorail structures has been estimated to be 1/3 to 1/4 the subway construction cost for the same transportation capacity which is one reason why Japan, which has limited space, is pursuing monorail development. (2) However, the capital cost of a heavy rail system built at grade is less than that of an elevated monorail as would be the cost of most light rail systems which are built at grade.

Operating costs of monorail vehicles is about equivalent to those of light rail vehicles which in turn are lower than those of heavy rail. However, since the heavy rail vehicles carry a greater number of passengers, the cost per passenger is about the same.

A summary to these comparisons is presented in Table 4. Included with the data for the monorail systems is similar information for two examples of heavy rail and two examples of light rail systems. It should be recalled that this is not intended as an equivalent comparison, but is included to

Table 4 Generic Transportation Comparisons

	Monorail			Heavy Rail		Light Rail	
COST	Tokyo	Seattle	Disneyworld	Atlanta	Washington	San Diego	Cleveland
Capital Cost (Million $)	33.6-61.5* +	8.5-11.6 +	UKN	1,499.4	2,698.8	94.4	109.2
Annual Operating Cost (Million $)	UKN	.6	3.4	49.1	116.1	3.7	8.0
CAPACITY							
Length (Miles)	8.2	1.1	14.2	14	39	16	13
Peak Hour Line Capability	45,000	10,000	10,000	48,000	63,000	4,000	12,000
Annual Passengers (Million)	UKN	2.1	5.5**	40.2	98.5	12.0	4.7
Annual Psgr. Mile (Million)	UKN	2.3	40.7	442.2	1,083.5	93.6**	44.7**
EFFICIENCY							
Capital Cost per Mile (Million $)	4.1-7.5	7.7-10.5	UKN	107.1	69.2	5.9	8.4
Capital Cost per Mile per Unit of Peak Hr. Capacity ($)	167	1050	UKN	2231	1098	1475	700
Operating Cost per Passenger Mile ($)	UKN	.26	.09	.11	.11	.04	.18
Operating Cost per Route Mile (Million $)	UKN	.5	.24	3.5	3.0	.2	.6
Implementation Time (Yrs.)	2-3	2-3	3-5	9+	12+	2.5	2.2

+Range due to different cost estimates from different sources

*Projected 1981 dollars using consumer's price index

Source: (3, 5, 6, 8, 12)

**Estimate

provide an idea or estimate of how the efficiency of a monorail compares to other transit modes.

SUMMARY AND CONCLUSIONS

Perhaps the most succint summary that can be made concerning monorails is that they are not substantially different from other rail transit modes. Monorail systems are not new nor is their usage in urban transit unique. The existence of transit lines in Japan attest to this fact just as the 81 year history of the Wuppertal line demonstrates the technology.

These foreign urban transit monorails have similar capabilities to most heavy rail systems. They have equivalent speeds and carrying capacities. Their U.S. counterparts, which are not used in urban transit, have scaled down carrying capacities which are quite similar to light rail systems.

The only characteristic of monorails that appears to be unique is the cost savings afforded under certain conditions. The structural costs of monorails are apparently lower than those of either subways or elevated, heavy rail systems. However, those savings are lost when comparisons are made with heavy or light rail systems built at grade. The operational costs are close to those of light rail systems which is probably due to their lighter vehicle construction. A more comprehensive study of these costs will be the product of the second task of this project.

The streamlined appearance of monorail and their novelty may serve to attract a higher ridership than some of the more traditional system. But, the elevated structure would undoubtedly bring complaints of visual obstruction and property devaluation. However, considering the elevated heavy rail alternative, monorails are smaller and less obtrusive.

These somewhat positive statements lead to the standard question; "if monorails are so functional, why aren't they being used for urban transit in this country?" There is no definitive answer to this question. Some plausible explainations may include:

1. Monorails have always been built and demonstrated in parks and fairgrounds and consequently have come to be associated with tourist type operations rather than transit.

2. Monorails are not a proven technology in U.S. urban transit. Frequently, they are dismissed without serious consideration simply because there are none around. Obviously, they cannot be proven in this country until one is built; the "Catch-22" of monorails.

3. There are a number of foreign and domestic companies that manufacture and market heavy rail systems but few that produce monorails therefore the marketing odds are against them.

It is understandable that transit authorities responsible for deciding where and how to invest enormous sums of money would be concerned with making the wrong choice. A decision to allocate funds to a system other than those traditionally selected could lead to a great deal of criticism. It would be ideal if these decisions could be made solely on the basis of sound performance and cost requirements. Unfortunately, the emotional and political climates do not always afford that opportunity.

One point is clear, transit officials need reliable information from which to work. A great deal of the information concerning monorails is outdated and current information is hard to obtain. The information that was obtained for this report indicates that monorails are not the universal panacea for urban transit problems that some of the enthusiasts seem to propound nor are they the useless folly their critics claim. Somewhere on the middle ground lies the objective appraisal.

SYNOPISIS

- Current monorail technology affords a safe, reliable means of providing an intermediate to large capacity as a single line or as part of a system.

- Monorail systems can be installed quickly along existing right-of-way with little disruption to traffic or commerce.

- Since these systems are elevated, their capital costs are higher than some light and heavy rail alternatives built using existing or at-grade beds, but are cheaper than elevated or sub-grade rail systems.

- While modern monorail technology provides a viable and competitive alternative in urban mass transit, it is by no means the optimal solution for every corridor.

- Each corridor must be considered in its own context, alternatives weighted, and decisions made based on future demands and resources rather than emotions and politics.

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