

THE FEASIBILITY OF MONORAILS

by

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ABSTRACT

The first monorail was built in 1821. Since that date the possible applications of one-track railroads have inspired many proposals throughout the world. Several lines have been built for both passenger and freight purposes. This thesis compares the physical and technical limitations of several types of monorail to present-day conventional transit in order to establish the feasibility of these monorails as a solution to modern transit needs.

Also mentioned are other applications of monorail such as one finds in industry.

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SUMMARY

A limited amount of literature is available on monorail. Much of the American and British literature is contained in the bibliography of this thesis. Of this literature, only a small percentage contains information useful for comparing monorail and conventional transit in regard to physical and technical limitations. The rest offers information of historical and other interest and can be contained in two appendices entitled CONSTRUCTED MONORAILS and PROPOSED MONORAILS.

Monorail today includes two suspended methods using one and two rails respectively. Also important is a supported monorail which overrides a beamway. The first and third types have been built in the past. Presumably, the second type can be built.

Comparison of these monorail types to conventional transit shows that the desired transit application determines the best alternative. That is, the first or second monorail types may be better for a downtown elevated construction because they are quieter, block less light from the street and use less right-of-way. However, conventional transit may be better for city-to-suburb lines where surface right-of-way is readily available.

Many characteristics are shared by monorail and conventional transit. The use of pneumatic-tired trucks as on the Paris Metro is one of these. Another could be the use of similar signal and control systems.

The preponderance of these physical and technical limitations shows that at the present, conventional rapid transit is better developed than monorail. Should monorail be further developed, then

the advantages offered by suspended systems will put monorail in a more favorable light. Again, this depends on the contemplated application. Presently, the supported monorail is the least favored alternative because it needs a comparatively massive track and support system. The type of guide wheel system it uses negates the possibility of decreasing the size of the track.

Constructing a prototype monorail that allows testing of loaded, full-size trains operating at intended design speeds requires a great deal of money. The author believes this is the largest difficulty now facing promoters of present day monorail. Parties interested in a Seattle monorail proposal include Lockheed Aircraft Corporation and St. Louis Car Company, both of whom may desire to finance a prototype monorail installation.

Alternative solutions to both monorail and conventional transit offer fewer advantages. Nor are they as developed as monorail and conventional transit. The industrial applications of monorail are extremely successful. While there is no modern monorail line or system serving public transit needs, it is expected that such a line or system is feasible in the future.

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PART I

INTRODUCTION

PURPOSE

The purpose of this thesis is to:

- A. Evaluate as much of the existing monorail literature as possible
- B. Present an accurate and current picture of monorail installations and proposals
- C. Decide which monorail type (s) merit closer examination
- D. Examine in detail the monorail type (s) chosen in "C"
- E. Compare these monorail types to conventional transit
- F. Compare these monorail types to other forms of transit
- G. Consider other applications of monorail

METHOD OF INVESTIGATION

Letters

After briefly examining available literature, the author made a list of additional possible monorail sources. The author then composed a general questionnaire which he sent in letter form to some twenty cities throughout the world. In each case the literature had linked monorail to the city questioned. Next personal letters went to three car companies and to persons prominently connected with monorail such as Edward Anson, Col. Bingham, Murel Goodell and Frank Lyon. Finally personal letters went to other interested parties such as Alweg and, indirectly, the British Transport Commission.

Bibliography

The volume of available monorail literature far exceeds that which the author expected. Both the British Transport Commission and the Bureau of Railway Economics furnished extensive lists of monorail references to the author. In many cases replies to letters were very useful.

The relative value of the references requires that they be split into three categories. Primary references, secondary references and references not used in the thesis. 13 of the 14 primary references are directly concerned with monorail and are so written as to yield valuable information to the thesis.

119 secondary references prove to be less valuable. These vary in value from very worthwhile letters that contain information in qualitative form to articles and press releases that use repetitious phrases, are lacking important facts and are written by people unfamiliar with the transit field. This resulted in much unnecessary work by the author. To spare the reader this effort the author describes the content of most references in the bibliography.

149 references not used in the thesis include those in foreign languages, those that are unobtainable and those that are too old to contribute to the thesis. The author's description of these last references may not be entirely accurate.

The entire 282 references represent the most recent and complete list of American and British monorail work known to the author.

SCOPE

Thesis

After reviewing the bibliography, the author had sufficient information to write the thesis and appendices. The most common fault of the articles and press releases contained in the bibliography is that they attribute to monorail characteristics common to any transit system. Because of this, the thesis tries to emphasize the basic physical and technical characteristics of monorail. It

compares monorail to conventional transit because:

- A. Conventional transit is very similar to and offers the most competition for monorail
- B. The reader who is familiar with conventional transit may compare monorail to other forms of mass transportation if he first knows how monorail compares to conventional transit

The author tries to present only enough detail as to establish the facts required by a reader who wishes to determine whether or not monorail is applicable to the particular situation he is considering. Because of the academic nature of a thesis, there is no attempt to prejudice the reader for or against monorail. It is the first such work on monorail known to the author.

Appendices I and II

Appendices I and II give an accurate and current picture of monorail installations and proposals respectively. As noted in these appendices, one should consult the book, UNUSUAL RAILWAYS (132), for the detail on built monorails and for a complimentary list of proposals including those prior to World War II. As presented, Appendix I gives the best brief but inclusive coverage of recently constructed monorails known to the author. Appendix II gives the reader a representative sample of proposals as derived from the literature written since World War II and available to the author.

Some information included in the thesis is duplicated in Appendices I and II. While repetitious this preserves the value of Appendices I and II as separate and complete lists.

HISTORICAL BACKGROUND

First Monorail

Henry Palmer of England built the first known monorail in 1821. The system carried foodstuffs for a British navy yard (132). In 1876 General Roy Stone built the first United States monorail known to the author. The short supported line spanned a gorge in Philadelphia's Fairmont Park where it was exhibited as a part of that city's Centennial Exposition (71).

America claimed the first passenger monorail four years later with the opening of the New York and Brighton Railroad. This line, connecting Brooklyn and Coney Island, failed within a year due to insufficient revenue (95).

At least thirteen operational monorails are known to the author excluding those used for industrial purposes. They include seven* which carried passengers, two** which carried freight and four*** with combined operations.

Successful Pre-World War II Monorails

Only two monorail systems have been successful. The first, Ireland's Listowel and Ballybunion Railroad, opened in 1888. It went without support until 25 years later and then closed in 1924 because of highway competition and mounting repair costs. The 9 1/2 mile freight and passenger line operated over a three-rail

* New York and Brighton, Boynton Bicycle, Tours, Schwebbahn, City Island, Tokyo and Disneyland

** Palmer, Sierra Salt Mines

*** Algeria, Tunis, Pegleg and Listowel and Ballybunion

track supported by 3 1/2 foot "A" frames. Its top speed was 27 miles per hour (131).

The second, called the Schwebebahn, was built in 1901 and is still in operation. It is a 9.3 mile suspended line for carrying passengers along Germany's Wupper River. 1,000,000,000 passengers have traveled the line in its 58 years of operation. This Wuppertal line, while still profitable today, is antiquated to the extent that it cannot be used for comparative purposes by this thesis (5).

Monorail After World War II

In the years after World War II the United States resumed commercial activity on a peacetime basis. This caused a huge increase in automobile traffic by the late 1940's. Highway and other transportation construction could not keep pace with this growth. Severe congestion resulted in many metropolitan areas, especially during rush hours. This started the inquiry into the inadequacy of existing transit systems. In turn came a revitalization of monorail concepts as a possible answer to the country's transportation needs.

Since 1950, six monorail demonstration lines have been built. These include two supported lines in Germany (84) (106), two suspended lines in Texas (66) (121), a supported line in Disneyland (29) (88) and a suspended line in Tokyo (6).

Besides the completed monorail demonstration lines are many proposed monorail systems. Two very recent proposals are:

- A. Northrop Corporation's Gyro-Glide. This single rail suspended monorail uses an inertial flywheel which generates power for the motors and provides stabilization for the car (93).

- B. Col. Bingham's Caracas transit study. This single rail suspended monorail uses a new, fast, lightweight switch (20).

DEFINITION

Monorail

Monorail is defined as a one-track railway. Vehicles using the railway are either suspended from or supported by the railway. As discussed in this thesis, monorail is primarily considered a type of public transit. It may operate either as a single line or as a network of lines which is called a transit system.

Conventional Transit

As stated previously in PART I, the thesis compares monorail to conventional transit. Conventional transit is defined as a two rail supported railway used for public transit. It also can be used as a single line or as a system. Conventional transit systems include those of Boston, New York and Chicago. They generally consist of subways downtown, elevated structures in intermediate areas and surface lines at their outlying boundaries. Usually this thesis uses the elevated type of modern transit proposals as a basis for comparisons to monorail.

MONORAIL TYPES

This section singles out three types of monorail for further consideration. The types were picked because they are, in the author's opinion, the most important today. The author also lists and discusses the other important types.

Suspended Monorail

The suspended monorail lines include two types. The first of these is the single rail of which the Wuppertal Schwebebahn (5), Dallas Skyway (121) and Tokyo Monorail (6) are examples. The cars are suspended by means of a hook-like construction and hang pendulum fashion from two tandem-wheeled trucks. These monorail lines are built to improve the hard riding and lateral oscillation found in conventional systems. This type was recommended to Los Angeles in 1954 (10) and to New Orleans in 1959 (9). It will hereafter be referred to as type I monorail.

The second suspended system is not a strict monorail but rather a dual rail, the rails being several feet apart. It is called a monorail, however, because of a single girder which carries both rails. There are two types of dual rail lines. The first type suspends the car from the outside flanges of the rails. This is called the Davino Duorail and is an adoption of industrial monorails. It is not considered by this thesis because it is very similar to the second type of dual rail monorail and has many of the same characteristics. The second dual rail type suspends the car from between the rails. This type was recommended to San Francisco in 1957 (11) and Detroit in 1958 (7) but has never been built. It will hereafter be called type II monorail.

Supported Monorail

A monorail car simply supported from below is unstable because the center of gravity of the car is above the rail. Without help, the car will balance in only one position. The means used to help

balance these cars divides supported monorails into two general groups. The first group uses a gyroscope to maintain balance. The Brennan Car (71) was a highly developed example which included a device for making the car tilt to the inside while rounding curves (131). This method of maintaining balance leaves the rider in constant fear of the gyroscopes stopping. Today, there is little interest in this type of supported system.

The second way to maintain balance is by additional guide rails. This was a feature of such systems as the Boynton Bicycle Railroad (19) in which a single guide rail was placed above the car. Necessary construction economy lowered the safety factor for the design of the "grape arbor" which suspended the overhead guide rail. This required motormen to operate at or near design speeds over curved sections. When speeds were higher or lower, the force of the car against the arbor became great enough to cause structural failure. After several accidents, the idea lost interest.

The Sierra Salt Mines Railroad (30) balanced the cars by two guide rails attached to the crossbars of the "A" frames used to support the main rail. This track was also used by the Listowel and Ballybunion (131). It was markedly noisy and rough riding because the cars oscillations could not be properly controlled. The resultant wear on both track and equipment also makes this system undesirable for modern transit.

A modification of the guide rail method of balancing the car, introduced by the Swedish Industrialist, Alex Lenert Wenner-Gren in Germany in 1952 (84) utilizes a car supported

from below by a precast concrete beamway. The top of the beamway supports drive wheels. A two-fifths scale demonstration model of this system operated until 1956 when a full-scale model replaced it (106). A four-fifths scale model operates in Disneyland (29) and other lines have been proposed for both Sao Paulo (49) and Seattle (122). This type of supported system is safer and smoother operating than the first three supported systems and will hereafter be called type III monorail.

PART II

REQUIREMENTS AND BASIC CHARACTERISTICS

CARS

This section considers the twelve cars described in Appendix III. Many statements about monorail advantages include characteristics applicable to any modern transit car such as all-round windows or resilient wheels. The following pages discuss only those requirements and characteristics that are peculiar to monorail cars.

Weight to Passenger Ratio

The major aim in monorail car construction is to reduce per passenger car weight to a minimum. This weight has been considerably lessened in conventional transit during the past years so that expensive horsepower could be more fully utilized. This is even more critical in monorail because the monorail track structure is quite sensitive to weight. If a weight of 170 pounds per passenger is added to the empty car weights for the Detroit and New Orleans proposals (Appendix III) their weight to passenger ratios become 960 and 730 respectively. This ratio compares favorably with the 1000 for the Chicago experimental transit car. All three of these compare favorably to a standard railroad car's ratio of 2000.

Car Construction

For the type I and II monorails the desire for a low weight to passenger ratio introduces serious car construction problems. In a conventional transit car and in type III monorail the live load or passenger load is transmitted to one integral load-carrying underframe. This underframe carries the car's dead load as well. The weight is then transmitted directly to the trucks. The car sides and roof are entirely secondary weight bearing

components and need only be designed for safety against collapse and telescoping during a collision.

For the type I or II monorail car, the live load is again concentrated on an underframe. The underframe must then transmit the load to the sideposts and the sideposts in turn must transmit the load to the roof. The roof then connects to the trucks, becoming the load-carrying member for both live and dead loads. The resulting construction makes it more difficult to eliminate sideposts for window space. More important, it makes for a totally new construction, one that will probably produce a greater weight to passenger ratio than a conventional transit car if the two are built of similar materials.

Hangers

Besides the weight difficulties in construction of the car itself, there is also a problem caused by type I and II hangers which in Tokyo's type I installation cracked after a year's operation and had to be strengthened (14). The Schwebbahn also had hanger trouble when it started (5). It is presumed that a similar difficulty could be experienced with type II. Several tests of type I and II cars will probably be necessary to determine proper design for a hanger arm of sufficient strength. Such a hanger does not have a counterpart in conventional transit where the underframe connects directly to the truck. It will be a source of extra weight for the monorail car.

Coupling

The type I and II car roof carries the car couplers as well as the side posts and hangers. Details of coupling for all three types

of monorail cars can be worked out as soon as the particular conditions contemplated for operation are met. All cars of Appendix III have individual propulsion units. This allows a relatively light weight connection (12).

If the monorail operation necessitates variable train lengths, as for transit and commuter service, heavier couplings are required. If trains are a set number of cars; simple, lightweight, semipermanent couplings can be applied. If car groups of two are semi-permanently coupled, and are then coupled by two-car units into larger trains, use of the heavier coupler is necessary (12).

As in conventional transit operation, couplers are easily adaptable to sharp radius curves where each car is in a different degree of superelevation. No problem is foreseen if the forward cars of a monorail train are leaving a curve while the rear cars enter it.

Weight Per Running Foot

Because monorail construction is particularly susceptible to weight conditions, a compromise must be reached between larger capacity and the relative weight increase necessary for construction of a bigger car. While it is desirable to keep car weight per passenger low from a power requirement viewpoint, it is desirable from a structural viewpoint to keep weight per running foot low. Therefore a long, narrow car is best (12). This will mean a stronger roof frame, to prevent sag, than would be found for shorter, wider, conventional transit underframes.

Cars in Appendix III are designed for about fifty passenger seats as a good compromise between power and structural

requirements. One car company states it is possible to build a fifty passenger, type I car at 40,000 pounds tare with 10,000 pounds more for passengers. A type II car would weigh slightly more (12) due to the heavier truck assembly. The type III car could be made lighter but as will be mentioned under Car Space, inefficient use of interior space still makes it the heaviest monorail car per passenger.

If a long and narrow car is advised, station platforms will be longer, causing correspondingly higher costs and longer passenger walking distance. Thus, a long, narrow monorail car presents another disadvantage in comparison to the two-rail supported car.

Car Shape

Advantages not peculiar to monorail cars include the type III, passenger-above, baggage-below scheme used by surface buses and modified front and rear car for the operator's controls as found on all of today's rapid transit cars.

The major difference in these end monorail cars is the plexi-glass, streamlined nose shown by artists (9) (10). The monorail car design must be compatible with the type of operation contemplated. If the application is commuting or rapid transit, the car must be generally symmetrical from an operational viewpoint. The car body should also provide the maximum useable passenger space in the minimum of cubical content. This is to reduce the pounds per passenger ratio. Thus radical streamlining should be avoided from the viewpoint of space utilization. The type III car is inefficient in this sense because its main wheel housings

consume central floor space at the car ends (12).

Air Effects

It is generally expected that air effects at the 50 - 60 mph speeds cited for most monorails in Appendix III will be negligible and will offer no different characteristics than conventional transit. Neither the type I monorail at Dallas nor the type III monorail at Cologne have trouble from air effects. Different effects include:

- A. Air-ground drag. None of the three monorail types have this effect if they are separated from surface traffic.
- B. Air-track drag. All three monorail types will have this effect. It may be only slightly less than that of a conventional type transit system.
- C. Streamlining effects which are small at speeds under 60 mph.
- D. Air-lift and air pocket effects. These are so small and infrequent that they may be excluded from the track design as well (12). If air-lift effects were large, they might aid monorail operation instead of hindering it.

Truck Assemblies

Truck assemblies for all type I and II monorails contain the car spring units and car hanger arm connections. Type III truck assemblies are enclosed in an inner frame which connects to an outer frame by means of spring and shock-arresting equipment. The type III outer frame is directly connected to the car body.

Truck assemblies include standard equipment from either the automotive or rail industries depending on whether the monorail used pneumatic or steel tires. The only problem is combining the parts effectively. Such things as proper drive ratios have to be

reached after experimentation (14).

Besides the standard equipment, types I and II offer mechanisms to combat undesirable sidesway. Type I can only dampen the sidesway to a predetermined maximum as controlled by truck stops. Type II can do as type I or can eliminate sidesway by rigidly connecting the car hanger to the truck. No experience with sidesway over 3 degrees is known but it can be expected that any sidesway whatsoever will necessitate the use of previously undeveloped equipment. This equipment will have to be extensively tested and will prove to be a source of trouble until experience with its operation is gained. The effects of sidesway on passengers is discussed under OPERATING CHARACTERISTICS, the effect on station approaches is discussed under STATIONS.

The type II steel-tired proposals offer additional advantages through a longer wheel base. These include better car weight distribution, good tracking and reduced flange pressure and wear.

However, the type II truck presents an added weight factor over the type I truck. One reference claims that this weight factor causes the type II car to lose any advantage it may have over the conventional truck (2).

Trucks for types I, II and III can not derail due to features inherent in the guide systems. This has been demonstrated by the Schwebebahn and by test lines in Germany, Japan and the United States.

Guide Wheels

Guide wheels, as attached to trucks for all types of pneumatic

tired monorails, tend to increase rolling friction. Flanges negate the use of guide wheels for steel wheeled type I and II monorail.

Type I pneumatic-tired monorail cars utilize eight 6.50-14 guide wheels per truck. Wheels turn in a horizontal plane against both sides of the beamway (9). The tires guide the two (6) or four (9) main drive wheels and regulate lateral vibration of the car on curves. This is done through spring connections to the hanger by lower wheels and to the truck by upper wheels (9). A Paris Metro pneumatic-tired guide-wheel system utilizes wooden rails instead of a steel beamway for both the main and guide wheels.

To guard against blocking tracks because of blowouts, the Metro uses hard-rubber-rimmed steel wheels which contact the running surface inside the path of the deflated pneumatic tire (46). This feature is included in proposed pneumatic-tired monorail cars (9). The pneumatic-tired guide-wheel systems should be considered applicable to both monorail and conventional transit.

Motors

All monorail cars designed since World War II are propelled by electric motors. An exception is the original Texas car which used two gasoline engines. For monorail types I, II and III the motors are mounted on the monorail car truck rather than the body, due to difficulties involved in suspension. The advantages gained thereby such as maximum starting torque, smooth acceleration, full horsepower utilization and reduced wheel slippage (7) are common to other rail systems. Motors can be of either the alternating or direct current type.

Alternating Current

Alternating current motors are three-phase, sixty cycle, 1800 volts (10). They include one-half and full speed connections. The one-half speed connection is used only under reduced speed conditions (10) (11). A hydraulic torque converter multiplies the starting power, permitting rapid acceleration. The alternating current motor eliminates the need for roadside conversion from public utility sources. If such a motor can be designed without additional car apparatus, then monorail costs could be considerably reduced. Otherwise the D. C. system would be used (32).

Direct Current

The direct current motors are 600-volt, series-wound, commutating-pole types (6) (9). One proposal uses groups of four motors in series for acceleration, changing to two in parallel between stops (9). The direct current motor has some advantage because of the wide range of available direct current equipment. This equipment has been proven by many mass transportation systems. It allows better prices, flexibility of equipment and good service, thus bringing about lower maintenance and operation costs.

If some doubt exists, as the conflicts of various proposals demonstrate, a study is advised. The emphasis of such a study should be on the comparison of initial cost of the longer-lived rectifying equipment for several substations versus the higher yearly maintenance and operating costs attributable to a less expensive motor installed in a great number of cars. Again, the car motor appears more critical than the rectifying equipment

necessary for direct current. Car motors present no large problem to monorail that is not present in conventional transit.

Contact Systems

The type I and II alternating current proposals use contact shoes against two wires hooked on insulators between the running rail and the car (7) (10). The direct current system uses two wires (9). Pickup for type II steel-wheel monorail could use the running rails instead of pickup wires if the signal system does not need them. Pickup for a pneumatic-tired direct current system needs a current collector for both positive and negative leads. For the Tokyo type I monorail, pickup is made with one pantograph per car contacting two twenty pound rails mounted upside down under the beamway. The type III direct current system uses shoes against two metal strips attached to the beamway sides. Monorail offers a definite saving over conventional transit in regard to contact systems for two reasons (11):

- A. At high speeds third rail operation is not as good as the much more expensive catenary pickup for conventional transit.
- B. Conventional transit lines hesitate to use third rail pickup where it may injure children. The types I and II monorail pickup is enclosed by part of the track and is too far off the ground to be touched by accident.

Research and Development

There is no question that either a safe, fast, light, spacious, or operationally comfortable monorail car can be built. Existing monorail lines demonstrate this. However, no all-inclusive combination of these features exists in one monorail car. The author feels that it will take further research and development to produce

a combination adequate for application in the United States. This opinion is shared by at least one consulting firm who advises its client to build a \$5,000,000 test section including two cars and a station (9).

TRACK

Description

Appendix III shows typical cross-sections of track for monorail types I, II and III. Type I track can be a tubular steel shape with a flat top or a welded rectangular box girder. Main wheel units override this single rail and guide-wheels contact the sides of the beamway if the line uses pneumatic tires instead of steel.

A box girder encloses type II rails. This girder opens at the bottom for car hangers. Cross bracing along top gives lateral stability between supports (8). The sides hold the running rails about four feet apart. They also take all vertical loads. Light-weight metal sheets protect the top and sides of the girder from adverse weather. Pneumatic-tired designs increase type II track structure by about fifteen percent (11).

A 55 inch high and 33 inch wide notched concrete beamway forms the track for type III monorails. Type III monorail design uses only pneumatic tires. The top of the beamway carries the main wheels and each side carries auxiliary guide wheels at its top and bottom.

100 feet is the average span for tangent sections of type I and II track while 50 to 80 feet is the average span for type III. Short radius curves reduce this span for all types. All three types can use single track installations. For types I and II the track

centerline runs about 9 feet from inverted "J" shaped supporting columns. For type III, the beamway runs directly above supporting concrete pylons. Double-track type I and II proposals place track centerlines nine feet on either side of "T" towers or eighteen feet apart. There is no information on type III double track. The bottom of type I and II track is about 25 feet above street level when separated from surface traffic and ten feet when on an inaccessible right-of-way. The bottom of type III single track is either sixteen feet above or directly at ground level.

Design Requirements

All three track designs include reasonable car, wind, earthquake (11), braking and acceleration (7), centrifugal, dead, collision (6), and installation loads (6). Designs also consider tensile, deformation and temperature stresses (9) as well as track deflection (8). Specifications of the American Railway Engineering Association (7) and American Association of State Highway Officials (9) govern the above for steel and pneumatic-tired proposals respectively. These requirements also apply to a later discussion of track supports.

For purposes of comparing it to monorail track the author defines conventional system track as including all rails, ties and girders, e c. down to the supporting columns. Even in a modern proposal (11) this structure has a larger dead load and is consequently more bulky than the type I and II monorail tracks. The type III monorail beamway, because of its all-concrete construction gives the most dead load of all.

Special Considerations

Type I and II steel wheel proposals fasten the rail to the girder with a resilient sound-deadening material (7) (10). On these types mitred expansion joints eliminate wheel clicking and furnish continuous support. In both type I and II the box girder is completely welded. Adjustable girder to support connections are included in type I and II designs to allow adjustment of horizontal and vertical alignments (8).

While the type II steel rails increase adhesion, they also increase size and costs over the type I track described above. The type II rail is similar to type III and two-rail supported systems because it can permit rigid frame support for cars. This prevents sideway and automatic banking.

All types of monorail track are easier to align than conventional transit. This is because the only place that the type I and II track can get out of line is at the supports where adjustable connections can be made. Also, the integral construction of the type III beamway and supports makes this the least subject to alignment troubles.

Necessary Tests

Designing and building an acceptable track for types I, II and III is possible as evidenced by both existing and proposed lines. However it is the author's opinion that test lines for types I and II must first show the ability to withstand deformations caused by the running of full-length trains at proposed speeds. The type II track must also show the ability to retain a constant gauge between the inside rail flanges as in conventional transit.

SWITCHES

Description

The hanger arms of type I monorail cars necessitate a switching method that provides space between tangent and turnoff girders. One proposal (10) uses a block with straight and curved track sections built up on either end. A dual motor actuates the switch by rotating the block 180 degrees. An improved type I monorail switch developed for Caracas engages steel wheels attached to the inside rims of pneumatic tires and carries the car through the points. It is much lighter than the first switch and takes less unsupported track length (20).

Type II and III monorail proposals use a transfer table with a tangent track section along one side and a curved track section along the other (11). The table is hydraulically operated. The Alweg two-fifths experiments used the only similar switch known to the author. A hand crank threw the Alweg transfer table.

Throw Time

The Schwebbahn uses a device to lift wheels from one track to another (5). This method is too slow for any installation which must maintain ninety second headways through a switch (2). The switch devices proposed for types I, II and III claim a three second change time with a repeat possible after ninety seconds. Present railroads and conventional transit systems operate with a throw time of two seconds and a repeat after ninety seconds. It appears that monorail can offer a switch that allows minimum desired headways. However no such switch exists today.

Whether or not a ninety second throw time is necessary is usually dictated by the layout of the track system. Should these tracks intersect or connect at points intermediate to terminals, then switches will play an important role in the capacity of the line. Many of today's conventional transit systems use walkover transfers instead. This is understandable from the viewpoint of capacity. If trains approach a switch on ninety second headways, they leave on 180 second headways or vice versa. However, if two lines intersect at a grade separation, then ninety second headways are obtained on both lines and capacity is doubled. Any disadvantage caused by inadequate monorail switches would therefore depend on where the switch was to be used.

Limitations

The author believes that in all monorail types:

- A. Switches will have to be developed and tested before their safe use can be advised.
- B. The initial costs of switches in relation to regular track or beamway will be higher than that of a standard switch to its railway.
- C. The operational costs will be greater for all but the Caracas monorail switch because more weight must be moved during each throw.
- D. A monorail switch will be more dangerous than a conventional switch in the case where a car accidentally passes through it and derails because the truck will fall to the ground. In types I and II, the truck could crush the coach beneath it.
- E. Pneumatic-tired switches will cost slightly less (8) because alignments do not have to be as exact as with steel rails.

The disadvantages inherent in monorail switches suggests that switches should probably be avoided on mainline operation. This will limit monorail because one can not build a system of intersecting lines but must keep individual train operations confined to a loop. It also limits freight and passenger operations involving sidings. However, many conventional transit systems also avoid switching in downtown areas and use walkover transfers instead. This means that the location on a particular line determines whether switches will cause disadvantages in terms of capacity.

SUPPORTING STRUCTURE

Description

Appendix V shows supporting columns for type I, II and III monorails. "I" or "V" shaped pillars with crossarms attached to track girders form "T" towers for carrying two-way type I and II monorails along the center of streets or private right-of-ways (10). A similar arrangement for single track lines employs an inverted "J" support and follows the curb line (7). Type III uses large concrete pylon supports which make it undesirable for application in built-up areas (114). Steel pillars could be a future alternative to type III concrete pylons. Such pillars would make the type III structure more desirable.

Design Requirements

Design requirements for supports are similar to those for track girders. Considerations governing design include the desired column spacing and the type of rail girder (9). Support design

considers clearance and longitudinal braking and traction forces for all monorail types. It also considers car sidesway for types I and II.

Size Of Column Bases

The moments imposed by track dead load and moving trains determine the size of the reinforced column bases characteristic of both monorail and conventional transit. Column bases for type I and II monorail are four to six feet wide and half again as long (1) (7). One writer claims that if the track girders on a two-way line are not crossbraced for their entire length, then the moments produced on each support by braking trains will require a six by fourteen foot base (2). This may be possible if two trains passing in opposite directions undertake maximum deceleration while at the same support. However this is not true at station platforms as the above author suggests. Nor is the train length as critical as the number of cars per train producing a moment on a particular support, remembering that this would be only two cars per train for a monorail line using fifty foot cars and a one-hundred foot column spacing.

If type I and II monorails and conventional transit both use a center support for two-way structure, then monorail column bases may be smaller. This rough assumption is based on the assumption that the dead load of the conventional track requires more support than the additional moment caused by a ten foot higher monorail structure. However, conventional transit has used the portal supports in all cases known to the author. This is less desirable because there are

two bases to hinder surface traffic instead of one. In type three, the concrete pylons are a combination column and base. The comments applied to type III tracks are also applicable to type III columns and bases. The present development of the type III pylon makes it more cumbersome and less desirable than either type I and II monorails or conventional transit in regard to use at downtown locations.

It appears that the lighter type I and II monorail structure will cost somewhat less than a conventional transit structure. In both monorail and convention transit it is reasonable to assume that two one-way structures will be more expensive to build than one two-way structure (2) (11). This makes loop service by both monorail and conventional transit structurally undesirable.

FOUNDATIONS

Foundation requirements are critical to monorail construction in two instances. First, if an alternative solution to monorail produces smaller bearing loads, then the choice of monorail will mean a larger, more costly foundation. As discussed under SUPPORTS, conventional transit will actually offer a heavier bearing load than monorail. Second, any differential settlements will cause alignment problems if they can not be corrected by adjustment at the track-to-support or support-to-base connection. Type I and II monorail track and support design permit this adjustment. The type III monorail and conventional transit supports, as presently designed, make such an adjustment difficult.

LOCATION

Alignment

All three monorail types offer an advantage over conventional transit in regards to alignment. A monorail train will, through the use of a single rail, be able to negotiate curves of 100 foot radius (9) and will be able to take curves of 1000 foot radius at sixty miles per hour (8). Pneumatic-tired monorail trains will be able to climb grades over ten percent and will be able to climb grades of four percent at sixty miles per hour (8). The advantages offered by alignment are far-reaching in terms of bypassing expensive real estate and otherwise conforming to restrictive downtown street layouts.

Land Use

Both type I and II monorails and conventional transit have small right-of-way requirements. Not only does monorail need less street area for column bases as discussed under SUPPORTS, but it possesses the correlary advantage of requiring less land. The type III monorail pylon requires the most land because of its larger base area and closer spacing. Type III virtually takes up a strip below its track equal to the width of the pylon bases. This makes it less favorable than type I and II monorail and conventional transit in terms of land use. Hamburg, Germany, turned down a type III proposal for just this reason (114).

The advantage of a small right-of-way requirement for monorail types I and II over conventional transit turns into a disadvantage

when the monorail line reaches less populated areas where real estate values decrease. Then, it becomes less expensive to build a conventional transit line and separate it from the surface traffic by a fence. The use of monorail here would mean unnecessary expense in terms of track girders and supports instead of the less expensive ballast and rails required by conventional transit. A San Francisco proposal advised against monorail because a large percentage of that proposal's track had inexpensive surface right-of-way available (11). This is a very important feature of monorail, one that precludes the use of monorail for city to city transit.

Aesthetic Considerations

Aesthetically, the choice of track location along a curb line or down a center mall is difficult. Exponents of curb lines declare that the central, two-track location is too bulky (4) (14) and acts as a roof over the street (1). Exponents of street center locations claim curb structures block light and air from adjacent building and weaken their foundations (1). Modern concepts of design make possible and attractive, solid-looking appearance that is no more bulky than necessary no matter which location is used. As mentioned under STRUCTURES, it is less expensive to use the street center location.

Use In Subways, On Bridges And Elsewhere

The total height of a monorail line including the motor, track and coach is greater than for a correspondingly constructed conventional transit line (10) (11). This means more excavation for monorail installations in tunnels, subways and open cuts (1) and a greater height clearance requirement for bridges and other locations.

It precludes extensive use of monorails in tunnels, in open cuts with tight overhead clearances and on lower bridge decks.

Conventional transit proposals usually use main boulevards. With the more liberal alignment requirements of monorail, it may be possible to locate in narrower streets or alleys depending on the particular layout of streets in the downtown area. This would mean less obstruction to store fronts and partial use of buildings for track supports with the resultant reduction in aesthetic cluttering of boulevards and in structure costs.

Other locations for monorail include highway centerlines, riverbeds and riverbanks. In any location monorail track could have secondary functions such as carrying street lights and utility lines. These other locations and secondary functions could be applied to a conventional transit structure as well.

Clearances

Monorail cars operating over streets or highways without center malls will collide with over-height surface vehicles (1). This collision hazard is peculiar to type I and II monorails. It could be overcome by overhead arches set just below the monorail car and placed to prohibit the entry of over-height surface vehicles onto streets with these overhead monorail lines.

Clearances at station platforms is discussed under STATIONS.

CONSTRUCTION

The installation or "turnkey" stage of monorail will be much longer and more expensive than conventional transit due to the necessary research and development of various parts of monorail as

discussed elsewhere in this thesis and as concluded by a conventional transit proposal (11). An example demonstrating the higher installation cost of monorail is the Tokyo test line which produced several design problems peculiar to monorail and needing further development (14).

If one or two monorail lines or systems are built and are adequate for a public transit service, then all subsequent type I, II and III monorail construction will be faster than for conventional transit construction. This is because conventional systems support two tracks by portal-type supports which cause added problems particular to such supports. Also, precast, shopwelded or prefabricated sections are more easily applicable to monorail (6), especially in relation to track sections. Monorail with its single supports will be much easier to construct than conventional, arch-supported transit in heavily populated areas. It will also be quicker because of the lower dead load requirement for monorail as discussed under TRACK.

OPERATING CHARACTERISTICS

Speed

In 1957 the Chicago Transit System experimental rapid transit train traveled at a top speed of 75 miles per hour (119). Examination of Appendix III reveals that type I and II monorails contemplate 60 and 70 mile per hour speeds. People in the transportation field feel this is the highest that can be expected without much higher maintenance costs or unpleasant riding characteristics (32). The Texas lines, the fastest type I monorails known to the author, reached 58.5 miles per hour on a short length of test section track (20),

The Alweg type III experiments reached 88 miles per hour, offering an actual speed higher than the CTS train. As pointed out in CARS, the type III monorail sacrifices maximum utilization of car space and weight. It also requires a more massive structure in comparison to types I and II and to conventional transit. So that, while it has sufficient speed, it is undesirable for other reasons.

While all monorail types can compete with conventional transit in terms of 60 mile per hour speeds, it is expected that higher monorail speeds will result in lost efficiency, added car weight per passenger and increased structure. This will hold true for conventional transit as well. Whichever alternative is least expensive at 60 mile per hour speeds should be least expensive at the higher speeds as well. However, there is no information available to prove or disprove this statement.

The previous paragraph could apply to extremely high speeds as well. It must be kept in mind that monorail or conventional transit capable of speeds in excess of 60 miles per hour can not be effectively utilized in city to suburb operations with closely spaced stops (2).

Therefore average speed is more important to a transit line than top speed in terms of passenger service. In Appendix III, proposed monorail cars give a rate of acceleration and deceleration comparable to the most advanced conventional transit system (10). Coupled with the top speeds previously stated, monorail should be able to compete with these systems on the basis of average speed.

Capacity

The number of people able to pass a given point on a transit line within a specified time is defined as the capacity of the line at that point. Capacity depends on car capacity, cars per train and train headways. For instance, sixty-passenger, ten-car monorail trains on ninety second headways can give an hourly capacity of 24,000 passengers. For comparison, New York subways on ninety second headways and using oversize cars can carry 55,000 passengers per hour (49). Comparable figures for other means of transportation are estimated as (15):

- 1,500 passengers in autos per lane on surface roads
- 2,600 passengers in autos per lane on limited access roads
- 9,000 passengers in buses on surface roads
- 30,000 passengers subway trains (average)

Thus a single monorail line as conceived today could answer all but the larger traffic demands. It could compete with conventional transit in most situations. Only two difficulties are foreseeable. The first would be one of switching. If the proposed system includes use of switches for mainline operation, then the more economical switches used by conventional transit would make monorail undesirable. Also, the author feels that breakdowns on mainline track could be more easily handled on a conventional transit system.

Skip-stop operation in the Detroit study (7) increases average train speed and reduces travel time. However it also increases intervals between stops at individual stations by a factor of two and can somewhat decrease capacity over the line. This however, is a result of the skip-stop-scheme and not the monorail.

On the basis of the size and speed of the Dallas line and the full-size Alweg experiment, as well as the signal systems developed

by American railroads, the author feels justified in saying that monorail types I, II and III present no special problems in terms of capacity.

Energy Use

Traction is a function of car weight and the coefficient of friction of the wheel and the running surface. Any monorail or conventional transit car gains added traction through the use of pneumatic tires. This is because the coefficient of friction of steel on steel is 0.2 while that of rubber on concrete is 0.8. Moreover, this figure for rubber to concrete could increase in time as tires deposit rubber on the running surface.

Additional traction is necessary only during emergency braking when wheel slippage can occur. Normal acceleration and deceleration are not critical in terms of monorail versus conventional transit traction. However, the type II monorail's closed track girder offers a slight advantage over type I and III monorail and over conventional transit because rain and soot can not reach the tracks to make them slippery.

Any decrease in rolling resistance means a subsequent reduction in operating power requirements. Monorail types I and III offer an insignificantly smaller rolling resistance than type II and conventional transit because of the fewer number and larger size of the bearings employed by type I and III cars. There are no appreciable energy gains by the type I and III monorail's concentration of weight on a single track.

Labor Requirements

Monorail installations by themselves offer no changes in labor

requirements. However monorail as a new system with no set pattern of labor contracts offers the possibility of reducing or eliminating operating crews and introducing the automatic operating methods now possible (32).

Safety

The problem of emergency stopping between stations (1) is questionable. The New Orleans study (9) continues train operation to the next station and the Tokyo monorail (6) includes a safety chute under each car. The author also suggests applying a safety chute like the ones used by commercial airlines.

Monorail operations present no other safety problems except derailment at switches as mentioned under SWITCHES and passenger safety at platform edges as mentioned under STATIONS.

General Stability

The section entitled CARS discussed air effects on monorail stability.

The center of gravity of the type I and II monorail car is well below the wheel to rail pivot point. This means the car will automatically return to a level position by any operation such as rounding a curve. The type III monorail car's center of gravity is higher than the top of the beamway upon which it travels. However, a suspension system connecting the inner and outer frames of the type III car to the guide wheels results in a smooth and stable operation. The Alweg type III car is a notable advancement over previous "one-rail" supported systems in respect to stability.

Monorail types I and III avoid lateral oscillation such as found in two-rail systems because all train weight is concentrated on one rail. Lateral oscillation is reduced in type II monorail in an amount proportional to the reduction in that type's track gauge.

Smooth riding characteristics were evident on the 88 mile per hour Alweg and the 58.5 mile per hour Texas lines. The author feels stability will be no problem peculiar to type I and III monorails. It will be less noticeable on a type II monorail than on a conventional transit system. Many feel that the oscillation of trucks on a conventional transit system prohibit it from obtaining extremely high speeds. There is no information available, however, which either refutes or confirms this conclusion.

Sidesway

Sidesway is a special type of stability problem peculiar to certain types of monorail operation. It is differentiated from banking found in conventional transit because in sidesway the car pivots pendulum fashion about the rail, type I, or about the truck, type II. The entire rail, truck and car is superelevated in banking. Sidesway can occur in type I and II monorails. Type I proposals include four slanted links connected with other members to restrain sidesway to a set value (9). This sidesway must be dampened sufficiently to remain within the design limits imposed by station platforms and other clearance requirements. Two type II proposals allow seven degree sidesway from the vertical (7) (11). Type II design also uses a group of snubbers that hold the car in a vertical position for approaches to station platforms, and during loading and unloading at the platform (7) (11). Other type II recommendations and the existing type III cars eliminate sidesway with a rigid frame support (2) and revert to banking to balance centrifugal forces on curves.

Various literature includes claims that sidesway would reach twelve degrees from the vertical (2), would cause passenger

discomfort (2), would build up oscillations (1) and would need to be dampened by gyroscopes (9). Mr. W. C. Wheeler, chief engineer of St. Louis Car Company, speaks of monorail sidesway as follows:

Sidesway requirements "could be rather readily determined for a given set of conditions. In both types I and II, the amount of sidesway encountered in operation will be the result of the curvature of the track on which the cars are operated, the speed of operation on those curves, and any wind pressures which would be in effect to either retard or augment the sidesway. While each of these three factors can be determined mathematically, they are applicable only to those specified conditions, and therefore, sidesway possibilities must be determined on the basis of the particular conditions under which each of the proposed cars would operate. The same general reasoning would apply to the type III installation, and the only difference between the three types would be the device or facilities that are proposed to limit or dampen sidesway."

"For types I and II, there are no devices, as such, generally applicable for restricting, cushioning, or retarding sidesway. It is the practice with the Wuppertal installation, and it has been proposed for similar installation elsewhere, that the cars are free to swing as a pendulum. The weight of the car and its attachment to the trucks results in a low frequency for this oscillation and under present operating conditions, the sway is much less than three degrees from the vertical. The Wuppertal installation is provided with a mechanical stop under the supporting rail beam so that the sway would be limited to three degrees. There has been no known instance where the cars

have swayed sufficiently to reach the limit stop. In the type I application, the truck is arranged to swing with the car, but, of course, in the opposite direction, so that the point of rotation is the wheel contact with the rail. In the type II application where the truck is supported on two adjacent rails with the car suspended between the rails, the truck, of course, doesn't move in respect to sway, as it is supported at four points and the sway center is determined by the center bearing location, which in most cases is above the wheel rail contact level. This would generally result in a longer arm for the pendulum and a correspondingly lower frequency of movement. The type III application being above the rail must have provision to provide stability for its operation on either curved or straight track, and therefore cannot be permitted to sway as is the case with the other two. It is necessary with this type to then cant the beam on which the car or train is supported so that the resultant from operation on curves is in line with the vertical centerline of the beam. This is similar, of course, to the present practice of elevating the outside rail of railroad curves and is for the same purpose. With the monorail, however, it is possible to provide for materially more deviation from vertical than can be obtained with the conventional outer rail elevation, and the Alweg experimental installation had provision for operation of their cars at a 45° angle on curves. This construction must be designed, however, for a given degree of curvature and a given speed so that under only those particular circumstances will the

resultant forces for the car coincide with the design beam centerline. On this account and also to compensate for wind pressures which are always variable and against which provision can only be made for maximum effect conditions, it is necessary to provide in the type III construction stabilizers which contact the sides of the supporting beam and thereby provide the reaction that maintains the car in the desired position above the rail....In all cases, however, they involve additional friction points, and usually rolling wheel contacts, both of which tend to limit the speeds available in operation, add to horsepower required, and involve maintenance....In all three types, it is possible to incorporate in the body construction designs which will tend to reduce side wind effects on swaying characteristics." (12)

The author concludes from Mr. Wheeler's remarks that:

- A. The 31 mile per hour Schwebbahn has no sidesway problem.
- B. Any sidesway of type I and II cars will probably present little passenger discomfort or other problems at speeds up to sixty miles per hour. No conclusion can be made, however, until a prototype installation complete with curves tests cars at desired speeds.
- C. Gyroscopes are not required for stabilization.
- D. Certain type II and all type III equipment will have no sidesway.

Mr. Wheeler's limit of three degree sidesway in each direction from the vertical and the need for sidesway elimination at station platforms is further discussed under STATIONS. Means of controlling sidesway is mentioned under CARS.

Noise

Modern transit equipment such as the P.C.C. car is virtually noiseless. There is no doubt in the author's mind that this can be true for future monorail and conventional transit installations.

Factors available to reduce noise include pneumatic tires, rubber-steel suspension equipment, resilient steel wheels, resilient material for rail to girder connections, quiet motor and drive methods and the use of acoustical material to line the inside of the type II track beam.

The noise of a monorail train traveling along a city street will be made by rail to wheel contacts and by motors. These points of noise generation are separated from the surface traffic by a greater distance in type I and II monorail than similar points in type III monorail and conventional transit. Also, the car body blocks the noise created by types I and II from the surface traffic.

The type III monorail contains and deadens noise within the motor housings and inner and outer frames. Conventional transit tends to reverberate this same noise between the underbody of the car and the street pavement. The author concludes that the noise level of monorails will be less than that of conventional transit when both use elevated structures. Noise levels in subways will be about the same for all kinds of installations.

Maintenance

Monorails lessen or eliminate certain maintenance costs of conventional transit. These include flange wear and track repair costs. Reduced flange wear is an advantage of type I and to a lesser degree, type II monorails. Besides track maintenance, type III beamway maintenance is less than that required by conventional transit.

Type I and II steel-tired monorail with some sideway could cause excessive rail wear on curves and other critical locations. Maintenance advantages offered by pneumatic-tires are applicable to both monorail and conventional transit. The author agrees with the president of the Schwebebahn (5) that monorail offers slightly reduced maintenance costs than conventional transit.

ECONOMICS

A monorail transit system is not operating today. Experimental lines do not give a fair prediction of costs (29). Several monorail proposals are out-dated in regard to costs (8) (10). No proposals give the method of computation for individual cost items. This lack of cost information causes the author to present very approximate figures. It will be impossible to deduce exact costs until a modern monorail transit line or system is built and operated for several years. Nor is it possible to make quantitative cost differentiations between various monorail types.

First Cost

Monorails claim a smaller first cost as their major advantage. Two recent monorail first cost estimates fall below the \$8,000,000 per mile (56) required by conventional transit. They are:*

Detroit (7).....\$5,000,000 per mile in 1958

New Orleans (9).....\$2,000,000 per mile in 1959

A San Francisco study (11) comparing monorail and conventional transit systems places the initial cost of monorail three percent

* Excludes right-of-way costs. Such costs could add thirty percent to the above estimates.

higher. The author feels that after monorail develops it can offer cost advantages over conventional transit, but only in the proper situation. For instance, the cost of monorail electrification in the San Francisco transit study was three-tenths that required by conventional transit because of the catenary installation necessary for the latter. In the same study, however, monorail yard costs exceeded those of conventional transit by seventy-five percent because conventional transit could more easily utilize existing facilities. The electrification and the yards each accounted for less than five percent of the total cost, making the effect of these items quite small.

Larger effects may exist between different monorail costs such as type I track structure versus type II, the latter being some fifteen percent more expensive. Or, between right-of-way costs for type I monorail and conventional transit, the latter being twice as large. Such effects are rather qualitative because no monorails built today prove these statements.

The following is a percentage breakdown of total cost as approximated from four proposals (7) (9) (10) (11):

Fixed Facilities.....	70%
track, switches, stations, yards, shops, construction costs, electrification, sub-stations, signalling, dispatching, etc.	
Cars.....	10%
Right-of-way.....	10%
General, administration.....	10%

Should it be possible to build a monorail for less than the cost of a similar conventional system, then monorail will be the cheapest-

costing large-capacity transit alternative that is separated from surface traffic. Costs for other means include (15):

Subways.....	\$20,000,000 per mile
Depressed Highways.....	\$10,000,000 per mile
Freeways.....	\$ 8,000,000 per mile

Cost of Maintenance And Operation

Maintenance and operating costs are usually given in dollars per car mile. They will be approximately the same for monorail and conventional transit (11). Two recent studies (7) (11) place this cost between \$0.50 and \$0.60 per car mile. Three studies (9) (10) (11) break this down as follows:

Maintenance of way and structure.....	10 to 15%
Maintenance of rolling stock.....	10 to 35
Operation of service.....	30 to 20
Power.....	40 to 20
General and Administration.....	10 - 10

Appendix VI shows that the direct cost of operating a transit system depends on the speed of operation (58). According to the appendix low operating speeds make trainman payrolls the controlling direct operating cost factor. High operating speeds make power the controlling cost factor. Only one monorail proposal (9) shows the influence of power costs at a higher operating speed.

As Appendix VI shows, any transit system using train crews should be designed so that the most economical balance between trainman payroll and power costs results at the average operating speed of that system. Also, the car and track design should be such that their maintenance costs are kept at a minimum equal to or below

present conventional transit systems. These new problems connected with greater power requirements at higher operating speeds are common to both monorails and conventional transit. The Schwebbahn reports that it has no heavy track maintenance and that operations produce little wear on rolling stock. However, this may be partially due to that system's low operating speed (5).

Comparison To The Automobile

Both monorail and conventional transit must offer time and money savings to the potential user. This section compares monorail operating costs to those of an automobile because it is the automobile that is replacing conventional transit today. If operation of a fifty seat monorail car costs \$0.60 per car mile at an assumed 40 percent load factor, then per passenger costs will be 3.0¢. An automobile operating at 6.5¢ per mile (13) with an assumed average passenger load of 1.5 passengers costs the user 4.3¢ per mile. Even if one allows for monorail costs not considered under Cost Of Maintenance And Operation, it still appears that a high-density monorail or conventional transit line can offer costs equal to those of the automobile user.

FURTHER STUDY

This thesis deals with monorail's physical and technical limitations. For that reason, the parts of the thesis dealing with economics and finance are very incomplete. Any further monorail study should consider these aspects in terms of the economic feasibility of monorail. It should attempt to show whether various aspects of monorail can be financed and how such financing shall be done.

Additional work on other aspects of monorail will be limited by the amount of new monorail ideas and new monorail construction. The outlook for both is good, and the author estimates that within the next five years at least two more small monorail lines will be built.

PART III

ADDITIONAL REQUIREMENTS

STATIONS

Location

Monorail stations for types I, II and III can be located at terminal areas such as city centers or airports (9) and at intermediate points such as bus terminals or shopping centers (9). They can be above or below ground, in the center or along the side of a street.

Most proposals contemplate two- or three-level stations located along the centers of major streets. The two-level station is usually proposed for a center mall. It includes a pedestrian underpass to sidewalks (8). The three-level structure raises the general rail elevation to permit a pedestrian crosswalk over street traffic to the adjacent sidewalks (8). In both arrangements the monorail tracks widen about twelve feet at the station area to allow the platform between them.

A possible disadvantage of the first arrangement is that people cross the street instead of using the underpass. The second type costs much more to build because of the higher, heavier structure necessary (10). The advantage gained from the higher station is its aid in starting trains into a downgrade and stopping them on an upgrade (10). None of these features of location differ greatly from those required by conventional transit.

Facilities

The layout for a proposed station can include turnstiles, change booths, escalators, concessions, waiting rooms, parking lots, rest rooms, public address systems, bus and taxi positions, freight

handling (9), closed circuit television for the stationmaster (11), and automatic train gates (9) (11). All of the above except train gates are applicable to conventional transit. The train gates are necessary for type I and II and possibly for type III monorails.

Platform Clearance

Type I and II monorails also differ from type III monorail and conventional transit in respect to platform clearance requirements. For instance a five car train will enter a station platform at about twenty-five miles per hour if it uses the high deceleration rates found in Appendix III. Should it have a tendency for sidesway at this point, the platform will have to either allow clearance for that sidesway or it will have to dampen the sidesway before the train enters the station.

The first alternative presents difficulty. If a train has a sidesway at any time while stopping or passing through the station it will mean that when the train is completely stopped and motionless it will not hang against the platform, but will leave an intervening space. This means a typical monorail car must be displaced 1.1 feet above and 3.0 feet to one side before it contacts the platform edge if the sidesway is allowed to reach fifteen degrees from the vertical. Also, the car floor will slope fifteen degrees. Should the sidesway be only three degrees, this displacement is still 0.2' up and 0.7' to one side (Appendix VI).

The Schwebebahn never exceeds the three degree limit imposed by stops on the car trucks when it approaches a station platform. No other existing type I monorail has platform approaches at

wayside stations. Once stopped, the Schwebbahn car is held against the platform by a bolster (5) so that boarding and departing passengers do not cause a rotation of the car and unsure footing. A recent monorail proposal suggests hooking the car to a rail running along the underside of the platform edge (9).

Whatever the arrangement, a hook or bolster will still have to displace about 50,000 pounds 0.7 feet to the platform edge for a three degree sidesway. Even if the clearance requirement is smaller, some device will still be required to bring the coach flush with the platform edge. While this problem can be solved, it will cost more per station than type III monorail or a conventional transit system.

A hook arrangement can also increase station stop time because passengers must wait until the train completely stops and the hooks become engaged before they can leave the train safely.

The second alternative, that of using a shoehorn extension of the station structure to reduce sidesway, requires additional structure for a distance of several hundred feet in the direction of train approaches. Such a platform extension would cause considerable friction between the train and the structure and would result in wear and passenger discomfort as the train oscillated from side to side. This alternative is also economically and aesthetically impractical (2).

The reader is referred to the section entitled OPERATING CHARACTERISTICS for further discussion of sidesway.

Passenger Safety

A second station problem is common to type I and II and possibly type III monorails, providing these monorails are built above a

street traffic. This is the drop-off at the platform edge. One solution is to deck the portion of the station immediately below this platform edge. This is expensive. A second solution is to rig a safety net across the area under the cars (5).

The third solution is to use passenger gates as introduced at Dallas and Tokyo and as proposed for other systems in the United States (7) (9) (11). These gates are to open and close with the car door. No mention is made of the timing involved or of the difficulties if a passenger is caught between the gate and the door. It would seem that a gate opening toward the platform could present a serious hazard to rush hour passengers.

At best, the problem will be eliminated after research and development of new equipment. As in the case of the device for holding the car against the platform edge, the time consumed in opening and closing the gates can also increase station stop time. In the author's opinion, the automatic train gate presents a problem of cost and time and should be carefully weighed against the extra cost of decking or the addition of a safety net.

To summarize, platform clearance and passenger safety at monorail stations will, in the author's opinion, cause type I and II monorail station costs and stop times to exceed those of conventional transit. At the least, both problems will require further research and development.

YARD FACILITIES

Yard facilities are usually designed so that all trains may be removed from mainline tracks. Therefore operating procedures on the individual transit system determine the yard locations. Other factors that have secondary influence on yard location include cost of available land, adjacent land use, utilization of existing transit yards and future facilities (11).

Functions of a yard include heavy repairs, inspection, lubrication, storage and washing (7) (8) (10) (11). The essential difference between types I and II monorail yards and those for type III and conventional transit is that the tracks lower the coaches to ground level so that repairs are easier and so that propulsion unit and truck access is possible from the top and sides. This also requires a light-weight, open girder for type II (8).

Collision maintenance and repairs are not necessary in monorail (8) or in any other transit system that is separated from surface traffic. The author is of the opinion that monorail yard facilities present no major problems in construction or operation. Their only disadvantage is that they can not utilize existing facilities as easily as conventional transit.

SIGNAL AND CONTROL SYSTEMS

The Schwebbahn has never experienced an accident due to signal failure (5). Recently proposed monorail systems resemble the Schwebbahn in that they have one-way operation along all main tracks. Characteristics of signal and control systems contemplated for type I

and II proposals are also similar to the signal and control systems used by conventional transit.

Most monorail proposals have automatic speed control which prohibits trains from exceeding a maximum safe speed. Its other features include:

- A. Slight brake applications as necessary on large radius curves
- B. Power cut off and automatic braking on smaller radius curves
- C. Allowance of minimum speeds while cars are in yards

Train headways are set by a head dispatcher at a fixed minimum such as ninety seconds. The train travels through a given block and automatic equipment prohibits entry of the next train into that block until the preceding train is a safe distance ahead.

The train operator always has a cab signal. He may be in full control of the train (10) or he may be necessary only for an emergency (9) (11). In the former system an operator can follow another train more closely, but at reduced speed. To do this, he first stops and acknowledges caution signals.

In the latter system, operation is completely automatic and is controlled by a central dispatcher. A specially qualified attendant may operate the train through a special control. This permits closer headways at peak hours. In emergency situations the regular attendant can radio phone the dispatcher who then permits the train in question to stop at the next station until the attendant gives a signal to proceed.

In all proposals the car automatically positions itself at the platform, the doors open for a set interval, then close and the

car departs. A safety refinement is a door which ceases its closing operation when an obstacle gets caught. The door remains stationary until the obstacle is removed (8).

All proposals contemplate a radio phone connection between the train and the dispatcher or station. Stations are in touch with the dispatcher as are the yards, power directors and substations (7). Type III has been operated from a roadside tower and from the car itself. No literature is available on actual or proposed type III signal and control systems but they are presumed to be similar to those for types I and II.

On the basis of past experience shared by railroads and conventional transit systems with equipment similar to that outlined above, the author feels that a safe and adequate signal and control system can readily be designed for any type of monorail.

POWER SUPPLY SYSTEMS

The power supply system for all monorail types includes a utility company input, voltage step-down process at a substation, an output from the substation to the "third" rail arrangement on the track, pickup by the train and conversion to energy by the train motors. The following comments deal with the input, stepdown and output.

Input current is three-phase, sixty cycle, alternating current at varying voltage such as 13,800 (9) or 2,300 (7) (10). This is transformed to 600 volt alternating or direct current at the substation.

Reference (9) gives a detailed account of one proposed alternating to direct current conversion. The conversion is necessitated only if the propulsion motors of the monorail car operate on direct current. The choice between alternating and direct current is discussed under CARS. The choice at the monorail car is presumed more critical from the standpoint of operation and maintenance and it determines the nature of the substation.

Substations can have two independent inputs (10) and can be operated from a central dispatching location as traffic requires (9). Impedance dropoff at track points between adjacent substations allow normal substation spacing.

Power supply systems for monorail are no different from those for conventional transit as far as input, stepdown and output are concerned.

PART IV

ADDITIONAL CHARACTERISTICS AND APPLICATIONS

ADDITIONAL CHARACTERISTICS PECULIAR TO MONORAIL

This section includes additional characteristics which the author feels are either advantageous to monorail or disadvantageous.

Advantages

Light

Any type of suspended or supported transportation system which separates traffic from the street below also blocks light to adjacent property. However, the monorail differs from conventional transit in several respects:

- A. The monorail structure is narrower than the elevated structure, giving a smaller shadow at any one moment.
- B. The monorail structure is more open, giving a feeling of spaciousness.
- C. The monorail structure is higher than the elevated structure. This means that the structure's shadow will travel along the ground faster, thus leaving any given spot shaded for less time.

Disadvantages

Finance

If the government will not subsidize monorail in its infancy as a new transportation system, then it is likely not to succeed.

Financing by other means offers the following problems:

- A. Public capital can not be used unless a majority of voters are convinced of monorail's worth to the community involved.
- B. The required initial research and development is too expensive for individual private interests.

- C. Any new group of private interest that plans to pool its capital first has to convince its members of monorail's success. The recent difficulties experienced by other forms of public rail transportation would make this task difficult.
- D. Equipment trusts are impossible because the banks would not have another monorail line to buy any equipment they repossess.

Integration With Other Systems

Type I and II monorails can not run on standard gauge track or convert to surface vehicles without complicated procedures such as disconnecting the car body from the trucks and placing it on a self-powered platform unit. Type III monorail may be more easily adoptable. In the early stages of the Alweg tests, the cars could leave the beamway and operate over a conventional two track system. If integration is not possible, monorail will require walkover transfers wherever it serves as a link to rail and surface transportation.

ADDITIONAL CHARACTERISTICS NOT PECULIAR TO MONORAILS

As stated in the INTRODUCTION, the author thinks that much of the available literature attributes to monorail characteristics applicable to any modern transit system. These characteristics include:

- A. Monorail as a supplement to automobiles and hence the highway system of a particular area.
- B. Monorail as a means to relieve "strain" placed on other transit systems such as bus, trolley and subway lines.
- C. Monorail as a means to sell or glamorize public transit, thereby retaining present and gaining new customers (16).

- D. Monorail as a means to gain quick access to downtown areas from nearby airports. While conventional transit could also be applied, there remains the question of actual need for such a line. A transportation thesis by L. Hammel, M.I.T. 1959, points out that because airports are relatively small traffic generators, the density of trips to any one downtown area is too small to merit a transit line.
- E. Monorail as a means of avoiding existing surface traffic through its own separate right-of-way.
- F. Monorail as a means for moving freight except as covered in OTHER APPLICATIONS OF MONORAIL.

REQUIREMENTS, NEEDS AND ALTERNATIVES FOR MODERN TRANSIT

Until now the thesis compares monorail to conventional transit. At this point the author would like to present the requirements for any modern transit system, places where such systems are needed and the alternatives to monorail and conventional transit. Because of their higher first cost, the subway and freeway are excluded from this discussion.

Requirements (47) (40)

Any modern transit system should require:

- A. Shorter home to transit line walking distances.
- B. Effective coverage in residential areas by frequent local service.
- C. Express service to the downtown area for the entire population.
- D. Parking facilities at all but the downtown stations.
- E. Seats for every passenger, even during peak hours.
- F. Fast, smooth, clean, comfortable, safe, air-conditioned and otherwise modern vehicles.
- G. Effective reduction in walkover transfers.

- H. Effective distribution in downtown areas.
- I. Origination to destination time better than that of an automobile.

Need

The Post-World War II demand for rapid transit is still felt in some twenty U. S. cities with populations from 750,000 to 1,500,000. The cost of conventional transit is prohibitive for these cities at its current figure of roughly \$8,000,000 per mile. Any system which can be built for less than this and which can demonstrate the capacity, related economy and the ability to attract passengers back from private autos will prove worthwhile. For all new systems including monorail this requires a prototype line for testing its physical and technical limitations (56).

Alternatives

The alternatives to monorail and conventional transit include:

- A. "Unibus", a method utilizing small light-weight buses which clamp onto a platform car running over railroad tracks from suburban dormitory to downtown distribution areas. "Unibus" combines advantages of mobility, speed and utilization of existing railroad right-of-ways. Its less desirable characteristics are increased car weight per passenger and wasted time in transferring the bus body onto the platform car (47).
- B. "Monobeam", a method similar to "Unibus" but without platform cars. The bus runs unaided on an overhead roadway by using guide wheels running against the side of the structure. This system requires a larger structure downtown, a structure resembling a two-lane elevated highway (38).
- C. "Piggybelly", a method whereby buses are suspended from a monorail-type track for trips to downtown areas. This allows the same flexibility as in the "Unibus". However time is wasted at distribution points while the buses enter or leave the monorail track. Also, car weight per passenger is higher and the track requirements are structurally greater.

The author feels that none of these three alternatives offer more advantages than monorail or conventional transit when the latter are combined with local bus feeder lines. Monorail has already been built on a test basis in several places throughout the world. It has a distinct advantage in terms of its present stage of development. If large structures are to be avoided in downtown areas, then any system with a greater structural requirement for the same capacity as monorail and conventional transit should be avoided.

OTHER APPLICATIONS OF MONORAIL

This thesis uses the comparison of monorail to conventional transit in order to establish the feasibility of monorail. However there are other possible applications of monorail besides that of public transportation. The thesis will discuss several of these.

Industrial Monorails (57)

The largest use of monorail principles exists in today's industry. These suspended systems feature many special devices for assembly line production. There are dipping machines for enameling and painting, transfer bridges for floor to floor movement, lift and drop sections for passing obstructions, turntables and switches for variable routing, elevators for heavy loads, scales for weighing and other automatic equipment.

Industrial monorails are extremely flexible as far as application is concerned. They may furnish varied service, completely automatic operation and heavy load carrying characteristics. Their

main advantage, however, is that they perform all lift and carry operations without load rehandling.

Military Monorails (78)

The accuracy and efficiency of modern bombing necessitates dispersed storage areas of smaller size in the future. It is claimed that a small portable monorail could make possible such dispersion, could be easily built with hand tools and could ~~alleviate~~ the need for clearing a right-of-way. It is further claimed that the system would not be subject to floods, would be easily dismantled when needed elsewhere and would be able to handle palletized loads.

Major problems apparent to the author include a suitable method of column support allowing speedy installation on varying terrain without increasing the shipping weight. If the monorail is to travel over longer distances and still have a large capacity, it will need two-way operation. This means complications regarding equipment turnaround and a further increase in the weight of the supporting structure. Such an application of monorail would have to be extensively developed before it would be suitable for military use.

Forest and Resource Development (133)

All three monorail types permit the builder to clear a more narrow right-of-way through undeveloped areas than that normally needed for a road. Nor does the horizontal alignment of the ground under the monorail have to be as good as a road.

To be weighted against these advantages are the following disadvantages:

- A. Other equipment will need to come in along the right-of-way to clear and construct the monorail line.
- B. A road will have to be built later.
- C. Monorail means transfer to other methods of transportation at its terminal points.

Port Facilities (78)

All three monorail types could be used to unload ships. With monorail there would be no need for expensive dock and wharf construction. Also if monorail were to extend further out from the shore, the problems of harbor dredging might be reduced.

The author's major criticism is that such a facility would furnish only as much loading and unloading capacity as permitted by the size of the cars used and the number of tracks between the ship and shore. Also, if type I and II monorails are used, they would have to be able to adjust to the level of the ships' deck or be built to be higher than the deck of the largest ship planning to use the facility. This is because these two types of monorails must be loaded from below.

So far, only the industrial application of monorail can be termed successful.

PART V

CONCLUSIONS

CONCLUSIONS

This thesis concludes that monorail types I, II and III can be constructed. In their present stage of development, however, they do not offer enough advantages in regard to physical and technical characteristics to compete with today's conventional transit. The problem of getting the necessary finance to develop a prototype line capable of proving or disproving monorail's usefulness in terms of public transit is most serious. If such a line is developed, it should prove that types I and, possibly, II can compete with conventional transit. This depends on the particular application.

This thesis offers the following supporting conclusions to the reader so that he may decide upon monorail in terms of the problem he is considering:

CARS

1. Type I and II cars necessitate new methods of construction.
2. Type I and II hangers add extra weight to cars.
3. Operation on short radius curves offer no problem.
4. Structural requirements limit passenger capacity of type I and II cars to about fifty seats.
5. Type III cars offer poor utilization of interior space.
6. Air effects are negligible on train operations under sixty miles per hour.
7. Monorail contact systems are less expensive than catenary systems used by conventional transit.
8. Further development of monorail cars is necessary before they may be applied to heavy density transit lines.

TRACK

9. Type I and II tracks permit rigid frame support of cars.
10. Type II track is fifteen percent more bulky than type I
11. Type III track is bulky because of guide wheel requirements.
12. All monorail track presents advantages over conventional transit in regards to alignment.
13. All tracks should undergo tests with loaded trains operating at design speeds.
14. A special problem of type II track is maintaining gauge.

SWITCHES

15. Monorail switches are not developed.
16. Monorail switches could offer three second throw times but would then cost more to operate than conventional transit switches.
17. Switches need not limit capacity of mainline operations.
18. Monorail switches may be more dangerous than conventional transit switches.

SUPPORTS

19. Type I and II supports use one base, making them less expensive than the arch-type conventional transit support.
20. Space requirements for the type III pylon supports make it the least desirable of monorail and conventional transit supports.
21. Loop service is undesirable for monorail and conventional transit because two one-way structures cost more than one two-way structures.

LOCATION

22. Monorails can operate over sharp curves and steep grades permitting less costly construction in downtown areas.

23. When neither monorail nor conventional transit needs a structure above surface traffic, then monorail types I and II still must use some structure, thereby increasing their costs.
24. Monorail requires a larger total clearance than conventional transit. This precludes its use in tunnels, subways, etc.
25. Type I and II monorail cars could collide with over-height surface vehicles.

CONSTRUCTION

26. Adequate development of monorail will be costly.
27. After development, construction could be quicker in densely populated areas than for conventional elevated transit.

OPERATING CHARACTERISTICS

28. Monorail trains can operate at sixty miles per hour.
29. Monorail offers adequate capacity for most cities.
30. Monorail may operate without train crews.
31. Sidesway can be dampened. It should offer little passenger discomfort at speeds up to sixty miles per hour.
32. Sidesway can be eliminated on some type II and all type III equipment.
33. At street level monorail will create less noise than conventional transit.

ECONOMICS

34. Available figures allow only rough approximations of monorail first cost and operating cost.
35. Generally, costs will be similar to conventional transit if monorail reaches a reasonable stage of development.
36. Monorail and conventional transit systems could offer cost advantages over the automobile.

STATIONS

37. Type I and II monorails require additional equipment for sidesway control at stations.
38. Type I and II monorails require extra equipment to protect passengers at station platforms.

ADDITIONAL CHARACTERISTICS PECULIAR TO MONORAIL

39. Monorail structures obstruct less light than conventional elevated structures.
40. It will be very difficult to finance a monorail line or system adequate for service comparable to existing transit lines or systems.
41. Monorail can not integrate with other transit systems. This means walkover transfers at junction points.

REQUIREMENTS, NEEDS AND ALTERNATIVES FOR MODERN TRANSIT

42. Monorail is better qualified to fulfill modern transit needs than "Unibus", "Monobeam" or "Piggybelly".

OTHER APPLICATIONS OF MONORAIL

43. The only successful application of monorail is to industry.

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Includes Listowel and Ballybunion, mentions Brennan monorail
- (281) Washington Post, "Some Curious Railways", Special Section, p. 5, October 1, 1916
Listowel and Ballybunion illustrated
- (282) Wood Preserving News, "A Monorail of Creosoted Timber", v. 1, pp. 115 - 116, July 1923

APPENDICES

APPENDIX I → CONSTRUCTED MONORAILS

This appendix summarizes most Monorails that have been built to date. It includes all that have been built since World War II. The reader is referred to UNUSUAL RAILWAYS (131) for a more thorough coverage of these and other monorails.

A DATE: 1821

BUILDER: Henry Palmer

LOCATION: England

PURPOSE: Transporting materials

TYPE: Overhead

DESCRIPTION: Rail, supported on wooden posts, carried two wheels, one behind the other. The wheels were connected by a cross yoke and hooks from the yoke carried the loads. The arrangement was horsedrawn.

COMMENT: This first monorail had little stability due to a high center of gravity. It was used for materials handling at a brickyard and shipyard.

B DATE: 1876

BUILDER: General Roy Stone

LOCATION: Over a gorge in Fairmont Park, Philadelphia

PURPOSE: Exhibit at Centennial Exposition

TYPE: Supported

COMMENT: First public showing of Monorail in U. S.

- C NAME: New York and Brighton Railroad
DATE: 1880
LOCATION: Bensonhurst, Brooklyn to Brighton Beach, Coney Island.
PURPOSE: Transport Passengers
TYPE: Supported on wooden frames
STABILIZATION: Auxiliary rails on crossbars of "A" frames.
COMMENT: Several steam locomotives were used. Operations
ceased, however, after one year because of inadequate passenger
revenue.
- D DATE: 1880's
LOCATION: Algeria and Tunis
PURPOSE: Transporting supplies at French posts
TYPE: Horse-drawn supported system with guide rails on the
sides of "A" frames.
- E DATE: 1886
LOCATION: E. Cambridge, Massachusetts
PURPOSE: Demonstration
COMMENT: Streamlined car disregarded as novelty
- F NAME: Boynton Bicycle Railroad
DATE: 1892
BUILDER: Boynton
LOCATION: E. Patogue, Long Island
PURPOSE: Experimental operation for promotional reasons.
TYPE: Supported on single rail and stabilized by two dollies
extending from the top of the car and turning in a horizontal
plane against an overhead rail.

SPEED: 60 mph operation and 100 mph capability

LENGTH: 2 miles

DESCRIPTION: The engine was two stories high and included an engineer upstairs and a fireman below. It was driven by a single 8' diam. wheel. The line operated for 2 years.

G NAME: Pegleg Railroad

DATE: 1878

BUILDER: Wilcox and Codington

COST: \$40,000

LOCATION: Ran between Bradford and Gilmore, Penna.

PURPOSE: Transporting oil equipment and some passengers.

TYPE: Supported on "A" frame and stabilized by two auxiliary rails at the crossbars of the "A"

SPEED: 30 mph

LENGTH: 6 mi.

DESCRIPTION: The track frame was 10' high and supported one of the lines three steam locomotives plus coaches

COMMENT: Oil excitement died after two years. At that time a faster engine was purchased to maintain profitable operation. The engine exploded on its first run, killing five people and ending further operations.

H NAME: Listowel and Ballybunion Railroad

DATE: 1888

BUILDER: Behr

LOCATION: Ireland

PURPOSE: Transport of passengers and goods.

TYPE: Supported on "A" frame with guide rails on either side of frame.

SPEED: 27 mph maximum, 18 mph operational

LENGTH: 9 1/2 mi.

DESCRIPTION:

Track The center 27 lb. rail stood 3 1/2' off the ground on "A" trestles supported by ties laid in trenches parallel to the line of travel. Draw-bridges were erected at highway crossings and the center rail was merely lifted clear. Trains easily negotiated 100' radius curves.

Cars There were 3 engines, 14 passenger cars and 24 freight cars. Each locomotive had twin boilers, fireboxes and cabs. Two cylinders powered the center of three coupled wheels located between the boilers. Passengers sat back to back on the cars.

COMMENT: The railroad operated until 1924 when highway competition and excessive repair costs caused its abandonment.

I DATE: 1894

LOCATION: Tours to Parnissieries, France

TYPE: Latrigue "A" frame supported with guide rails.

J NAME: Schwebebahn (swinging railroad)

DATE: 1901

BUILDER: Eugen Langen

LOCATION: Wuppertal, Germany

PURPOSE: Transport of passengers within and between two industrial communities.

TYPE: Single-rail suspended system

SPEED: Maximum allowed operating, 31 mph. On a test section before construction 47 mph was reached for a 300' radius curve and 94 mph was estimated as possible for a 1200' radius curve.

LENGTH: 9.3 miles.

DESCRIPTION:

Track 6.25 mi. over the Wupper River includes sloped latticed box girders spaced at 80' to 110' with every sixth girder fixed in the form of a double "A" frame to compensate for longitudinal stresses. These are bridged by horizontal steel plate girders which in turn support the rail 39' above water.

The remaining distance has the rails 26' above the ground where it is carried by a portal type structure running down the streets

Cars Original cars are 37 1/2' long, 6 3/4' wide and 8 1/2' high. They carry 50 passengers and weigh 12 tons. Twenty new cars purchased in 1951 can carry 70 passengers because of their lighter weight and 7' width.

The cars are powered by two 2-wheel tandem bogies per car operating on worm-driven 59 hp. motors from a 600 volt D. C. current supply rail.

Operations Traffic volumes are 4,200 passengers per peak hour in each direction. The operating headway is two minutes and two-car trains are used.

COMMENT: This line is still operating profitably and without an accident due to derailment or structural failure. It has carried about 1,000,000,000 passengers.

K DATE: 1908

BUILDER: E. W. C. Kearney

PURPOSE: To test method of stabilization

TYPE: Supported by running rail beneath car and stabilized by an overhead guide rail kept in contact through telescopic adjustment controlled by compressed air.

COMMENT: Introduction of idea of low pressure on stabilizing rail due to car's low center of gravity, this pressure going to zero as car reaches design speed. Difficulty is incurred at curves where vehicle must be driven at exact design speed or undue stress occurs in guide rails.

Venture gained inadequate support and no commercial installations were undertaken.

L DATE: November 10, 1909

BUILDER: Richard Scherl

LOCATION: Zoological Gardens, Berlin, Germany

PURPOSE: Exhibition

TYPE: Supported on single rail and stabilized by gyroscopic means

COMMENT: A 6-passenger car and a short length of track was shown.

M DATE: November 10, 1909

 BUILDER: Louis Brennan

 LOCATION: London, England

 PURPOSE: Exhibition and Experiment

 TYPE: Supported on single rail and stabilized by a
 gyroscope only.

 SPEED: 22 mph.

 DESCRIPTION: A 40' ten-ton 40-passenger car ran on 70 lb.
 rail by using two 3'-6", 1,500 lb. gyroscopic wheels
 rotating in opposite directions at 3000 rpm. The car
 operated on gas-driven generators furnishing power for
 propulsion and for the gyroscope motors.

 COMMENT: 10 years of subsequent experiment were necessary
 to perfect a superelevation of the car as it rounded curves.
 Fear of the gyroscope stopping kept this and the Scherl
 vehicle from being used for public transportation. 125 mph.
 speeds were predicted to be possible.

N NAME: City Island Railroad

 DATE: 1910

 LOCATION: City Island, Bronx, New York City

 PURPOSE: Carrying passengers from a nearby suburban New
 Haven Railroad Station to City Island.

 TYPE: Supported on single rail and stabilized by two over-
 head D. C. power feed rails hung from a "grape arbor"
 structure

 SPEED: 50 mph possible

COMMENT: Due to the arbor collapsing at the outset, as caused by a motorman rounding a curve below its design speed, the railroad was restricted to 15 mph. It failed in a few months when a conventional two rail line was built paralleling it.

O

DATE: 1921

BUILDER: Russian Government under direction of P. P. Schilouski

LOCATION: Leningrad to Tsarskoe Selo

PURPOSE: Experimental to be used for passengers

TYPE: Supported on single rail and stabilized by gyroscopic means.

SPEED: **Very** low

LENGTH: 20 miles

COMMENT: 7 miles were built by 1923, at which time the project was abandoned due to lack of funds and mechanical resources.

P

DATE: 1924

BUILDER: Sierra Salt Corporation

COST: \$350,000.

LOCATION: 150 mi. east of Los Angeles in Saline Valley, Inyo County, California

PURPOSE: Hauling magnesium salts and equipment to the Trona Railroad

TYPE: Single rail supported on "A" frame and assisted by guide rails at the junction of the "A" frame crossbar.

SPEED: Maximum over 35 mph, comfortable operation at 15 mph.

LENGTH: 30 miles

DESCRIPTION:

Track 50 to 80 lb. rail bolted to 6" by 8" riding beams connected each "A" frame. The "A" frames were spaced at 8' intervals, had a 6" by 8" vertical member and held both 2" by 8" and 8" side rails, the 2" by 8" being held by the horizontal crosspiece.

Equipment Unique rectangular frames supporting pairs of double-flanged wheels were used for engines and cars. Each gas-powered Fordson engine could pull two cars. This three vehicle combination would haul a total of 19,400 lbs.

Operations Balance was excellent and sway negligible at 15 mph. However, there was excessive noise and wear as partially caused by steel guide rollers hung on vertical shafts by tension springs. The line included 12% grades and 40' radius curves.

COMMENT: Monorail was used here to offset high grading and steel costs. Line was abandoned in 1927 when the salt mine could not produce on competitive basis.

Q NAME: Bennie Railplane
DATE: 1929
BUILDER: George Bennie
LOCATION: Milngavie, near Glasgow, Scotland
PURPOSE: Experimental
TYPE: Suspended from single rail

COMMENT: The streamlined diesel electric car was driven by airscrews at either end. Its bogies hung from a lattice girder track on steel trestles placed at 80' intervals. The car was credited with negotiating 1/25 gradients over its short section of track.

R

NAME: Alweg 2/5

DATE: 1952

BUILDER: DR. Axel Lennert Wenner-Gren

LOCATION: Fuehlinger Hyde, Germany

PURPOSE: Test and Exhibition

TYPE: Supported on 4 pneumatic tires and stabilized by guide wheel running along the top and bottom of each side of a beamway

SPEED: 93 mph max.

LENGTH: 6,400' oval

DESCRIPTION:

Track Prefabricated concrete beam carries 5 tracks, each of flat steel, one on top for main bearing and 2 on each side for stability. Superelevation and transitions are cast into the 10" wide reinforced beam.

Beams are supported by reinforced concrete pylons up to about 8' high and 20' apart. Minimum radius on curves is 444' while the maximum banking is 45 degrees.

Cars A 3-car train was tested, each car being about 30' long, 10' wide and 12' high. The cars consist of an inner frame rigidly connected to the body and suspended from the outer frame in which the drive wheels are mounted. A car is powered by an electric motor on each of its two 2-wheeled bogies. Electricity is collected from a pair of current supply rails slightly below and on either side of the beamway.

Operation Trains were automatically controlled from a central off-track cab permitting minimization of headways for maximum track capacity.

COMMENT: The 2/5 actual size system has subsequently been replaced by a full scale test oval.

S NAME: Houston Skyway

DATE: 1956

BUILDER: Monorail, Inc., Murel Goodell, Pres.

COST: \$100,000

LOCATION: Arrowhead Park, Houston, Texas

PURPOSE: Promotion of Monorail

TYPE: Suspended single rail

SPEED: Limited to about 50 mph by track length

LENGTH: 880'

DESCRIPTION

Track The 30" diameter tubular track has a flattened top 18" wide. A vertical flange 6" high and 1/2" wide is welded down the center of the flattened top. The

guide wheels contact both sides of this flange. The track is welded to 18 30' "J" shaped, ball bottomed steel towers spaced 55' center to center and sunk 16' into the ground.

Car The 26,760 lb. air conditioned 54' long, 8' wide, 7' high coach seats 60 passengers and is powered by two 310 hp. Packard engines. One engine rides at the center of each of the two 4-tired bogies. 8 smaller guide wheels center the drive wheels by turning in a horizontal plane against the 6" track flange. The operator sits above the rail in an unlimited view bogie-mounted cockpit.

COMMENT: This first monorail to run in the U. S. since 1927 has been moved to Dallas. By 1957 Monorail Inc. had built and tested a supported system at this Houston site.

T NAME: Dallas Skyway

DATE: 1956

BUILDER: Monorail, Inc.

LOCATION: Cotton Bowl, Dallas, Texas

PURPOSE: Experimental and Promotional

TYPE: Suspended single rail, improved version of Houston Skyway

SPEED: 58.5 mph, 100 mph claimed for 1800' curves but limitation is imposed by length of track

LENGTH: 1600'

COMMENT: Changes after Houston included development of a "T" tower for two-way operation, 150' span between two towers and an improved beamway. No sidesway and little sense of motion was felt at top speed.

U NAME: Alweg
DATE: September 1957
BUILDER: Wenner - Gren
COST: \$1,500,000
LOCATION: Fuehlinger Hyde, Germany
PURPOSE: Test and Exhibition
TYPE: Supported and stabilized by horizontally mounted wheels
running against a grooved beam.
SPEED: 50 mph operation, 150 mph claimed.
LENGTH: 1.25 mi. including three turns and an incline
DESCRIPTION:

Track Beam 55" high, 33 3/8" wide, with grooves on
either side spanning 15' high pylons at 40' intervals,
includes single and double section switches.

Car Articulated two-car trains, each car 37' long,
10' wide, the cars having room for 30 sitting and 70
standing passengers, negotiates 15% grade is electrically
powered.

COMMENT: 16 linear yards of track per hour were built during a
speed-up construction experiment.

V NAME: Tokyo Monorail
DATE: October 1957
BUILDER: Tokyo Metropolitan Government
COST: \$100,000
LOCATION: Tokyo Zoological Gardens
PURPOSE: Test monorail for use in Tokyo
TYPE: Single rail suspended

SPEED: 20 max., 8.5 mph operational

LENGTH: 1200'

DESCRIPTION:

Track A shallow trough on the upper surface of a box girder carries the bogies. The girders and their 23 inverted "J" supports are built up from sheet and angle steel, the rails being fabricated to the proper curvature in the shop.

Cars 30'-6", 6-ton cars seat 31 passengers. The omission of an inner shell and the use of wrap-around windows lessens the total car weight. Trains are each two cars with rounded ends for the operator.

Bogies The cars are hung from two rubber-tired bogies, each bogie powered by one 30 kw motor. Power pickup is by pantograph from a 600 v. D. C. source under the running beam. Cars are kept in alignment by four smaller spring loaded tires on each bogie. These tire turn in a horizontal plane against the outside of the rail girder.

COMMENT: Low labor costs, construction from stock steel and use of standard transit parts resulted in a low cost. After 11 months of operation the demonstration line has developed several bugs including cracks in car hangers, warping of the asphalt running surface and undue wear on the drive gears. The cracks were braced and the asphalt replaced with concrete. As of June 17, 1959, however, Tokyo had still not decided to go into a full scale monorail system.

- W NAME: Disneyland Alweg
DATE: 1959
BUILDER: Alweg Corporation
LOCATION: Anaheim, California
PURPOSE: Transport visitors through "Tomorrow Land"
TYPE: 3/4 size of Fuelinger Hyde Alweg
SPEED: 25 mph
LENGTH: 3/4 mile
DESCRIPTION: Line includes 7% grades and a maximum height above ground of 35'. Two three-car trains are operated over a "circle-8" route at two minute headways. Train is electrically driven by means of a bus bar mounted on the side of the beamway and is quiet and smooth in operation.
- X NAME: Monorail from Senate office building to Capitol
LOCATION: Washington, D. C.
COMMENT: One of several small passenger-carrying Monorails throughout the world used for special purposes.
- Y NAME: Industrial Monorails
DESCRIPTION: Usually an overhead system with or without electric powered motors and employing many special devices to fit its particular task.
COMMENT: Very versatile for materials handling, found in large and small manufacturing plants.

APPENDIX II - PROPOSED MONORAILS

This section contains a representative list of recent monorail systems which have been proposed but not built. Notable exclusions include the 1959 report for New Orleans (9), the 1958 report for Detroit (7), the 1957 and 1956 reports for San Francisco (11) (8) and the 1954 report for Los Angeles (10). These reports are easily obtained and are thoroughly covered in the body of the thesis. The reader is referred to UNUSUAL RAILWAYS (131) for coverage of Pre-World War II proposals.

- A NAME: Railplane
DATE: 1950
PROMOTER: John A. Hastings
LOCATION: Long Island
LENGTH: 120 mi.
PURPOSE: Furnish commuter service from Montauk Pt. to Manhattan
TYPE: Single rail suspended
SPEED: 150 mph.
COST: \$60,000,000
COMMENT: Reported trip time including 13 station stops is 45 min. Right-of-way cost is estimated at \$25,000 per mile. Fares will be \$1.00 maximum, \$0.25 minimum.
- B NAME: Uniline
DATE: 1951
PROMOTER: Unknown British Engineer

LOCATION: Bengal, Nagpur

PURPOSE: Replace railroads by reducing their costs through simpler right-of-way and less rail

TYPE: Rubber tired Alweg type running on top with guide rollers along side of 3' wide track

COMMENT: Characteristics of system include rolling friction coefficient of 0.8, sharp curves and steep grades allowable, and 44 tons per mile less rail needed, than on a conventional system

C DATE: 1951

PROMOTER: Los Angeles Metropolitan Transit Authority

LOCATION: Over Los Angeles River from San Fernando Valley to Long Beach

COST: \$1,500,000 per mile

COMMENT: Authority had no means of raising funds

D NAME: Airail

DATE: 1951

PROMOTER: Piasecki Aircraft Corp.

PURPOSE: Solve metropolitan and inter-urban transit problems by separating vehicles from ground traffic and propelling them at high speeds

DESCRIPTION: Propeller driven car suspended from cable-like rail supported by series of suspension bridge structures

COMMENTS: Advantages claimed include:

(a) minimum capital expenditure

(b) minimum installation outlay

- (c) minimum interference with surface area below rail
- (d) capacity to use or cross rights of way such as
turnpikes, railroads
- (e) safety

E DATE: 1955

 PROMOTER: Alweg

 LOCATION: Cologne, Germany

 LENGTH: 20 mi.

 PURPOSE: Connect Cologne and Opladen

 SPEED: 26 mph. avg.

 COST: \$1,400,000

 COMMENT: Offer of Alweg to build 2 1/2 mi. experimental section
at its own expense connecting a suburb and the Leverkusen Chemical
Works, made on condition that Cologne would let building permits
by a given date

F DATE: 1955

 PROMOTER: Peter Masfield

 LOCATION: London

 LENGTH: 10.25 mi.

 PURPOSE: Connect London Airport and downtown area

 TYPE: Suspended and enclosed by boxed girder

 DESCRIPTION: Low noise level, electrically-powered 2,000 bhp
motors for carrying 150 passenger units and making trips in 5
minutes on 10 minute headways, using 15 minutes to unload
at each end

 SPEED: 150 mph.

COST:

\$ 27,000,000 track, terminals, and stations
2,400,000 7 monorail units
1,400,000 signalling and electrical equipment
2,900,000 purchase of right - of - way
300,000 other

\$ 34,000,000 installation cost

\$ 540,000 track
230,000 coaches
28,000 signalling equipment
57,000 land
5,000 other

\$ 840,000

\$ 840,000

110,000 annual rates
1,550,000 interest on capital at 4 1/2%

\$ 2,500,000

470,000 275 employees
430,000 maintenance materials

\$ 3,400,000 Total Annual Cost

COMMENT: Complete cost analysis includes calculation of \$1.40 fare charged to break even at 80% load factor using 101 road trips per day necessitating 8,800,000 passengers per year

(\$0.14 cost per passenger mile). Masefield believes Monorail must have characteristics above, be used for short high density routes, and pay for itself before its use will prove advantageous.

A proposal similar to Masefield's but more detailed as to coach and track design appeared earlier in 1956.

G DATE: 1956

PROMOTER: Monorail Incorporated

LOCATION: Fort Lauderdale to Miami

Fort Worth to Dallas

New York to Albany

New York to New Haven

New York to Philadelphia

COMMENT: Suggested by Goodell and Bingham as intercity applications of Monorail, no formal proposals known.

H DATE: 1956

PROMOTER: Monorail Incorporated

LOCATION: Hypoluxo, Florida

LENGTH: 1250 feet

PURPOSE: Carry light density passenger traffic from U. S. 1 to James Melton's "Autorama".

TYPE: Single rail suspended with 26 passenger coach

COST: \$75,000

COMMENT: Line has not been started

I DATE: 1957

PROMOTER: Herbert Crover, President, Monorail Corporation of New Jersey

LOCATION: Asbury Park, New Jersey

PURPOSE: Run along boardwalk for tourists

TYPE: Single rail suspended similar to Dallas

COMMENT: Proposed financing included direct payments on initial installation from percentage of passenger revenues

J DATE: 1957

PROMOTER: Earnest A. Herzog, Boston Society of Civil Engineers

LOCATION: Boston, Massachusetts

PURPOSE: Relieve traffic congestion to downtown areas

DESCRIPTION: 52,000 lb., 110 passenger cars to be 60 ft. long, 9 ft. wide and 8 ft. high inside

COMMENT: Proposed routes would radiate from city center along main transportation flows.

K DATE: 1957

PROMOTER: Alweg Corporation

LOCATION: British Columbia

LENGTH: 400 miles

PURPOSE: Transport of passengers, timber and ore

TYPE: Alweg

SPEED: 150 mph.

COMMENT: Part of proposed development project, would connect Yukon in the north with existing Canadian railways. Reloading at railroad transfer point necessary. Similar project in Southern Rhodesia given up due to internal problems of that country.

- L DATE: 1957
- PROMOTER: Alweg
- LOCATION: Mexico City
- PURPOSE: To connect city with proposed 200,000 person
 industrial suburb
- M DATE: 1957
- PROMOTER: Monorail, Inc.
- LOCATION: Philadelphia
- LENGTH: 7 1/2 mi.
- PURPOSE: Replace Red Arrow tramcar service between Media and
 69th street
- TYPE: Suspended single rail with thirty passenger coaches
- COST: \$600,000 per mile
- COMMENT: Philadelphia Urban Traffic and Transportation Board
 states that the advantage of newness monorail offers is offset
 by necessary transfers. Also, no need exists as area has an
 adequate 330 miles, grade separated network of commuter
 railroads
- N DATE: 1957
- PROMOTER: Alweg
- LOCATION: Sao Paulo, Brazil
- LENGTH: 63 mi. system including:
- 30.5 mi. elevated track
- 23.0 mi. surface level track
- 8.0 mi. subway
- 1.5 mi. tunnel
- PURPOSE: Establish a transit system

COST: \$150,000,000

COMMENT: System includes 124 stations, construction was slated for 1958

O DATE: 1958

PROMOTER: Backers of \$200,000,000 jet airport

LOCATION: Burlington County, New Jersey

PURPOSE: Transport passengers to New York and Philadelphia

SPEED: 250 mph.

P DATE: 1958

PROMOTER: Member of municipal committee studying proposals for improving city's transit system

LOCATION: Melborne, Australia

Q DATE: 1958

PROMOTER: Sir Alfred Bossom

LOCATION: London

PURPOSE: Connect city center to airport

TYPE: Alweg adoption, capable of leaving beamway and converting to a bus at the airport

DESCRIPTION: 50 passenger, self-powered, 12 ton cars with 130 hp. motors on each bogie run in units of two or three on short headways and without intermediate stops. They run on two way Alweg type track utilizing existing railroad rights of way. A ground level track goes around the airport, avoiding terminal and making possible direct connections to the aircraft.

SPEED: 100 mph.

COST: \$23,000,000

COMMENT: Proposal eliminates need of fixed structure at the airport, cutting expense. British Ministry says any system contemplated must be thoroughly tested before being opened for operation

R DATE: 1958

PROMOTER: Southwest Redevelopment Commission

LOCATION: Washington, D. C.

LENGTH: 3/4 mi.

PURPOSE: Redevelop S. W. Section as tourist attraction

TYPE: Suspended single rail

COST: \$4,000,000

COMMENT: Line to have started at Capitol area, go through southwest section, pass Pentagon and terminate in fringe parking lot. In a July 1959 transportation survey submitted to the President, monorail was not recommended because of the substantial supporting structures and unfavorable cost comparisons with ground level rapid transit construction

S DATE: 1959

PROMOTER: Basildon Development Corporation

LOCATION: Basildon, England

LENGTH: 1 1/3 mi.

PURPOSE: Research and development

TYPE: 51 passenger car of light weight alloys and plastics

T DATE: 1959

PROMOTER: Cleveland Transit System

LOCATION: Cleveland, Ohio

LENGTH: 2 1/2 mi.

PURPOSE: Connect airport to rapid transit terminal

COMMENT: Financial organization of C. T. S. makes rapid transit extensions impossible. Monorail transit, though one of several ideas considered, does not have accurate construction and operating costs available to interest the necessary private capital according to C. T. S. official

U DATE: 1959

PROMOTER: N. Anderson, Dualrail and Monorail
Developing and Engineering Service, Inc.

LOCATION: Denver, Colorado

PURPOSE: Developing rapid transit service

COMMENT: Proposal declined due to inadequate need at present time. Proposals by Monorail, Inc. and Alweg in 1957 were also considered and rejected by an eight man committee

V NAME: Gyroglide

DATE: 1959

PROMOTER: Northrop Corporation

PURPOSE: Rapid transit applications

TYPE: Single rail suspended system

DESCRIPTION: Features propulsion and gyro stabilization unit requiring no power supply system between stops. Includes 1000 lb. high speed inertial flywheel which turns generator. Generator supplies current for traction motors until next stop is reached and station supply builds up flywheel speed. Long runs would require intermittent electrified sections. Idea is reportedly used by buses in France.

- W DATE: 1959
- PROMOTER: Alweg
- LOCATION: Hamburg, Germany
- PURPOSE: Supplement existing transit system
- COMMENT: City officials decided against Alweg as the supporting
pillars were undesirable in the densly built-up city.
- X DATE: 1959
- PROMOTER: Monorail, Inc.
- LOCATION: Houston, Texas
- COMMENT: City will further consider monorail when Monorail, Inc.
submits a report now under preparation
- Y DATE: 1959
- PROMOTER: Unknown
- LOCATION: Toronto
- COMMENT: Toronto Rapid Transit Commission deems monorail unacceptable
in congested districts of Toronto for the following reasons:
- (a) installation on main streets is unsightly
 - (b) towers obstruct traffic
 - (c) overhead stations would blanket adjacent stores, hurting
their retail trade
 - (d) width of Toronto sidewalks makes access to stations difficult
 - (e) noise level would be unacceptable
 - (f) rush hour loads claimed to be beyond the capacities possible
with monorail
 - (g) monorail furnishes no great economy

Z DATE: 1959

PROMOTER: Lockheed Aircraft

LOCATION: Seattle, Washington

LENGTH: 4800 ft.

PURPOSE: Carry passengers from edge of city center to Century
21 Exposition site

TYPE: Single rail supported system similiar to Alweg

DESCRIPTION: Three four car 96 passenger trains at 22,000 lbs.
per car

SPEED: 60 mph.

COST: \$5,000,000

COMMENT: Seattle Transit System mentions presence of several
roadblocks such as financing before construction contract is
signed. Primary reason for choosing monorail is public interest, line
will serve as a test operation for future mass transit plans in
Seattle.

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CAR CHARACTERISTICS

	S A N	S A N				S T L					C H I C A G O	
	F R A N C I S C O	F R A N C I S C O	L O S A N G E L E S	N E W O R L E A N S								A L W E G
D E T R O I T	'57	'56	S	S								

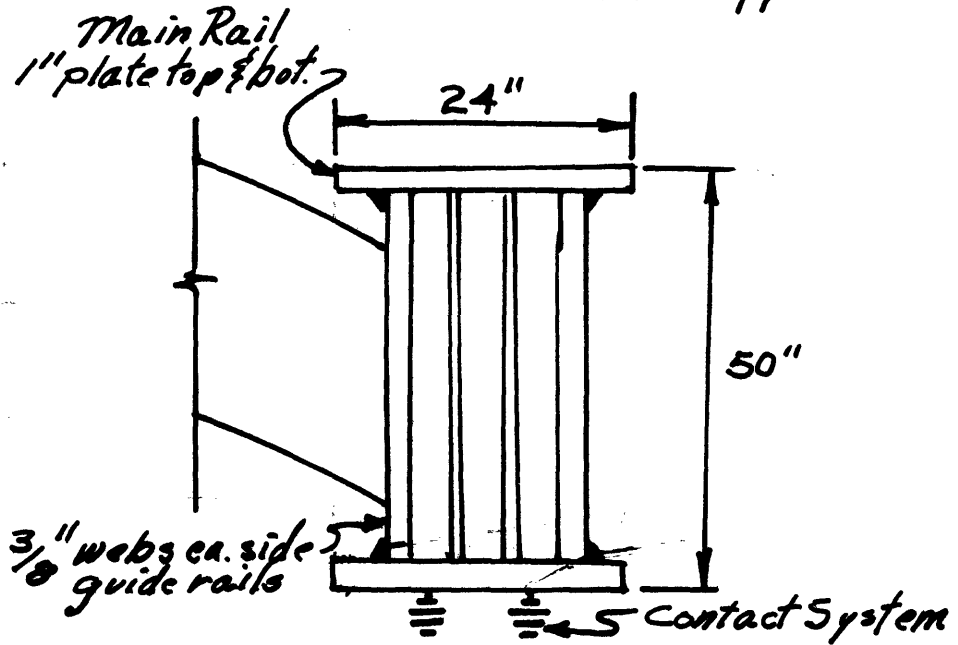
TYPE	II	II	II	I	I	I	I	I	I			III
LENGTH FT.	58		70	50		53	28	54	38	59	48	37
WIDTH FT.						7	5	88	7	10	9	10
HEIGHT FT.			9			11	7	7	9	12	12	
DOORS PER SIDE	2	2	2	2		2	2			4	2	
SEATS	65	32	76	67	50	50	31	60	50	65	50	30
TOT. PASS.		100			lim							100
TRUCK CENTERS						30	15			45	34	
TRUCK BASE FT.	9						4			7	6	
WHEEL DIAM. INCHES	26			30						34	26	
CAR WEIGHT TONS TARE	25		30		14	20	6	14	12	42	22	
NUMBER OF MOTORS	2	4	2	4	2	4	2	2	2	4	4	
HORSEPOWER EA. MOTOR	200	100	200	100	100	100		310	59	100	100	
ACCEL. IN FT/SEC ²		3.5	4.5		2.0					2.5	3.2	
BRAKING IN FT/SEC ²		3.5	4.5		3.0					3.0	3.2	
TOP SPEED MPH			75	60	60		20	50	31	55	76	50

RAIL CROSS-SECTIONS

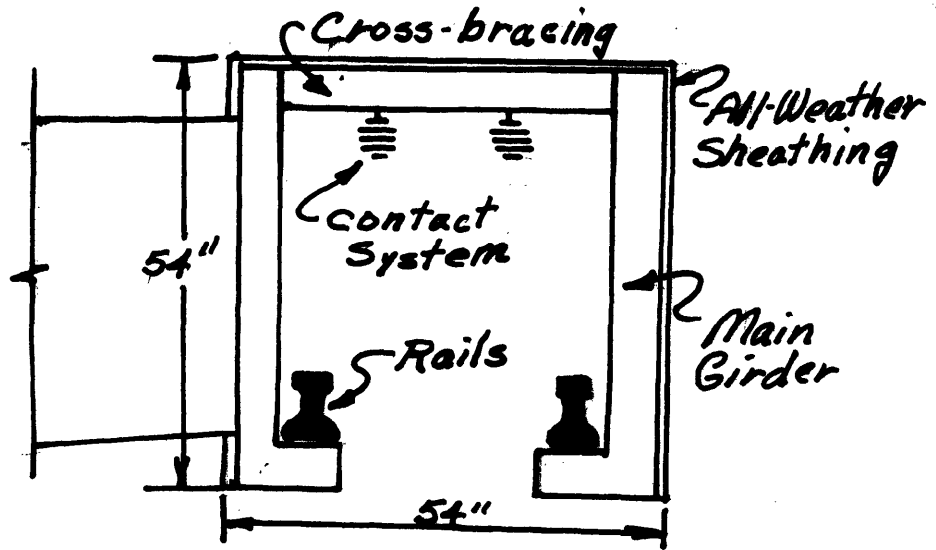
Not to Scale

Dimensions Approximate

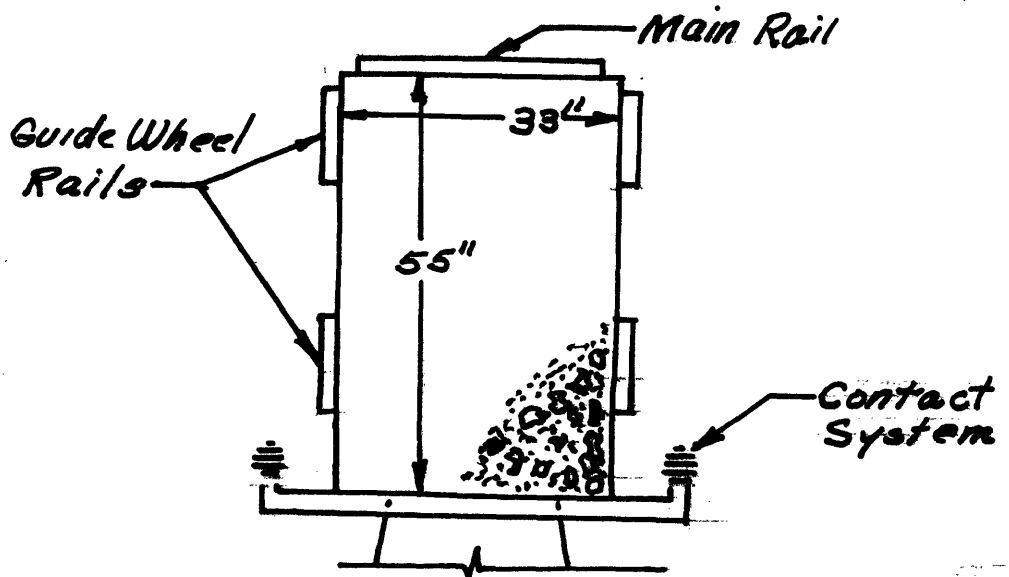
Type I
Pneumatic-
Tired



Type II
Steel
Wheels



Type III
Pneumatic-
Tired

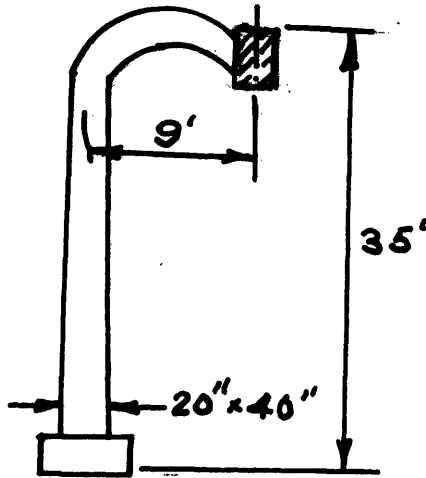


RAIL SUPPORTS

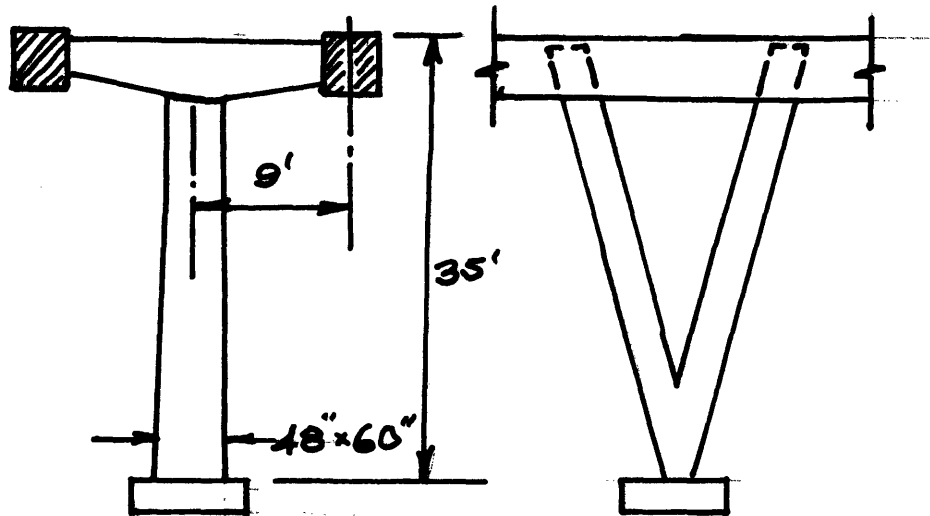
Not to scale

Dimensions Approximate

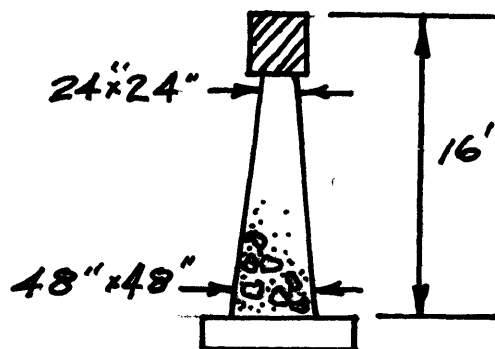
TYPES I & II
SINGLE-TRACK
SUPPORT

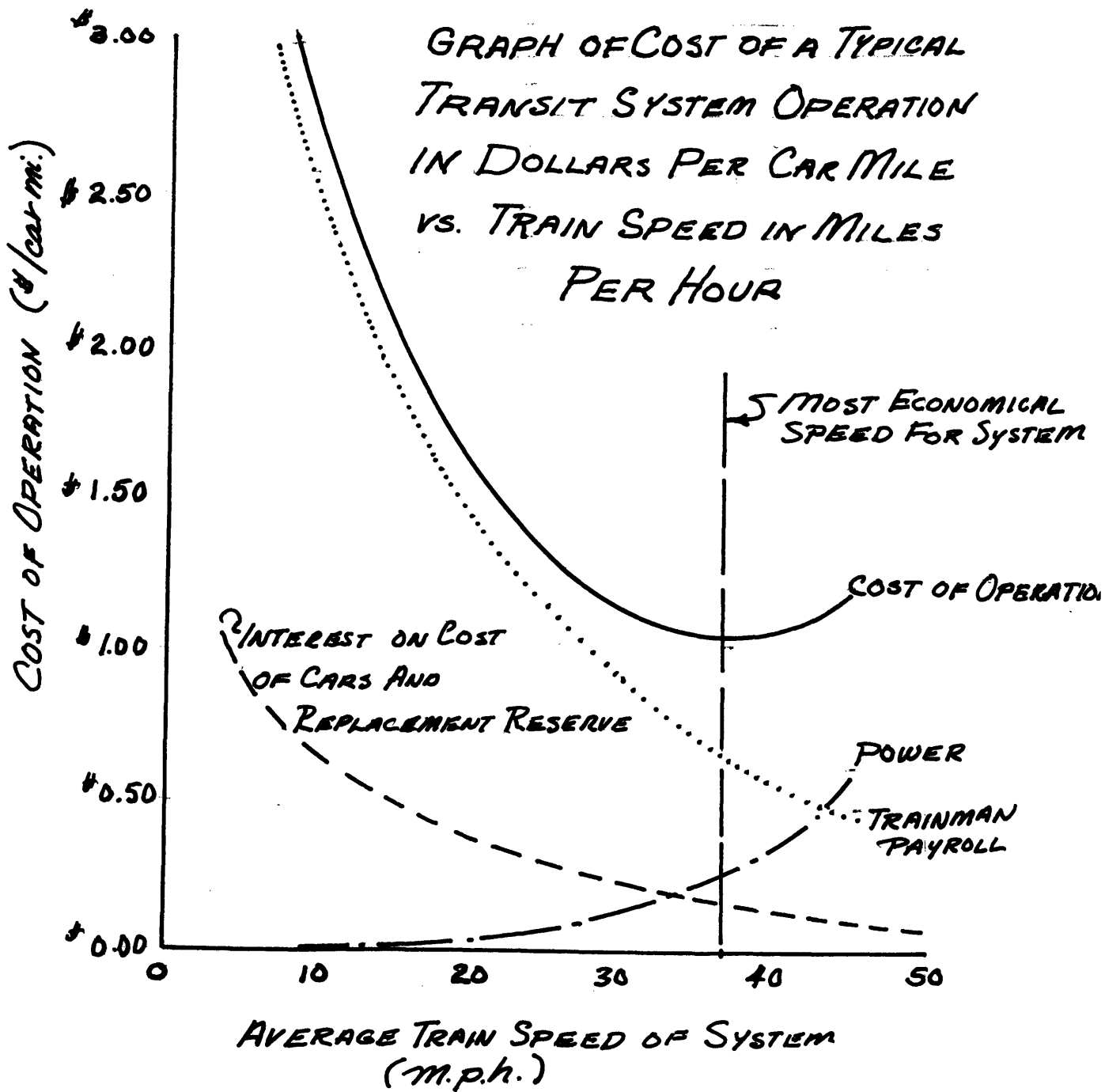


TYPES I & II
DOUBLE-TRACK
SUPPORT



TYPE III
SINGLE-TRACK
SUPPORT





PLATFORM CLEARANCES

Scale $\frac{1}{2}'' = 1'-0''$

