

Design and Evaluation Criteria for Stations of Magnetically Levitated Trains

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Abstract-Application of magnetically levitated trains (maglev) has attracted numerous transportation industries throughout the world. Maglev stations are centers for planning, traffic attraction, and preparing the fleet. They definitely play a key role in any maglev system. The annual increase in passenger numbers and increasing willingness to use maglev systems indicates the necessity of professional designs for stations. Despite this necessity, no well-accepted report has been presented for the design and evaluation criteria of maglev stations yet. Therefore, a systematic approach is required for this methodology. For this purpose, the research provides a comprehensive overview of the design and evaluation criteria for maglev stations, including structures, equipment, and facilities. Moreover, primary activities at maglev stations are investigated and evaluated. In addition, this paper has tried to adopt a proposed algorithm considering the needs and volume of passengers. These studies facilitate planning and development of maglev stations. Based on this approach, passengers will face stations with appropriate area, the acceptable service and welfare space. This will answer the growth of passenger traffic in maglev systems and attract more passengers.

Keywords- *Magnetic Levitation; Magnetically Levitated Trains; Maglev; Guideway; Station; Design Criteria; Maintenance; Land Use*

I. INTRODUCTION

Magnetic levitation (maglev) is a highly advanced technology, and it has various uses. The common point in all applications is the lack of contact without any wear and friction. This increases the efficiency, reduce maintenance costs and increase the useful life of the system. The magnetic levitation technology can be used as a highly advanced and efficient technology in various industries. There are already many countries attracted to maglev systems. Contrary to the traditional railway trains, there is no direct contact between the maglev vehicle and its guideway. These vehicles travel along magnetic fields that are established between the vehicle and its guideway. Therefore, these vehicles can travel at very high speeds. The replacement of mechanical components by electronics overcomes restrictions of conventional railways. The manned maglev vehicles have recorded the speed of travel equal to 581_{km/hr} [1-4].

Stations have emerged as a new central place in metropolitan cities. They have become the hub of networks due to their high accessibility by different modes of transport in high scale level. They produce movements that offer sufficient opportunity for the development of commercial land use [5-7]. Railway stations entered a new age again in the late 20th century after the introduction of high-speed railways (HSR) [8, 9]. Stations play a very important and influential role in maglev transport systems. The efficiency of maglev systems over the national and regional development depends on stations. The development hub of maglev systems was mainly formed around the stations. Despite the high complexity of maglev technology, possible unforeseen demands in the future and the lack of comprehensive statistics and information, the proposed methodology in this research can contain all the future needs along with the development of international politics.

II. MAGLEV STRUCTURE

Maglev suspension systems are divided into two groups of ElectroMagnetic Suspension (EMS) and ElectroDynamic Suspension (EDS). The three primary functions in the maglev technology are levitation, propulsion, and guidance. The performance of EMS systems is based on attractive magnetic forces, while EDS systems work with repulsive magnetic forces. In EDS systems, the vehicle is levitated above the track using repulsive forces. In EMS systems, the vehicle is levitated above the guideway using attractive forces [10].

The guideway is the structure that maglev vehicles move over and by which maglev vehicles are supported and guided. Its main roles are to direct the movement of the vehicle, to support the vehicle load, and to transfer the load to the ground. It is the main element in maglev systems and holds big share of costs for the system. Guideways can be constructed at grade (ground level) or elevated on columns. Elevated guideways minimize land occupation and prevent collision with other forms of traffic at-grade intersections. Elevated guideways occupy the least amount of land on the ground. Guideways are designed and constructed as single or double tracks. The Fig. 1 shows standard guideway types for the EMS system [11-15].

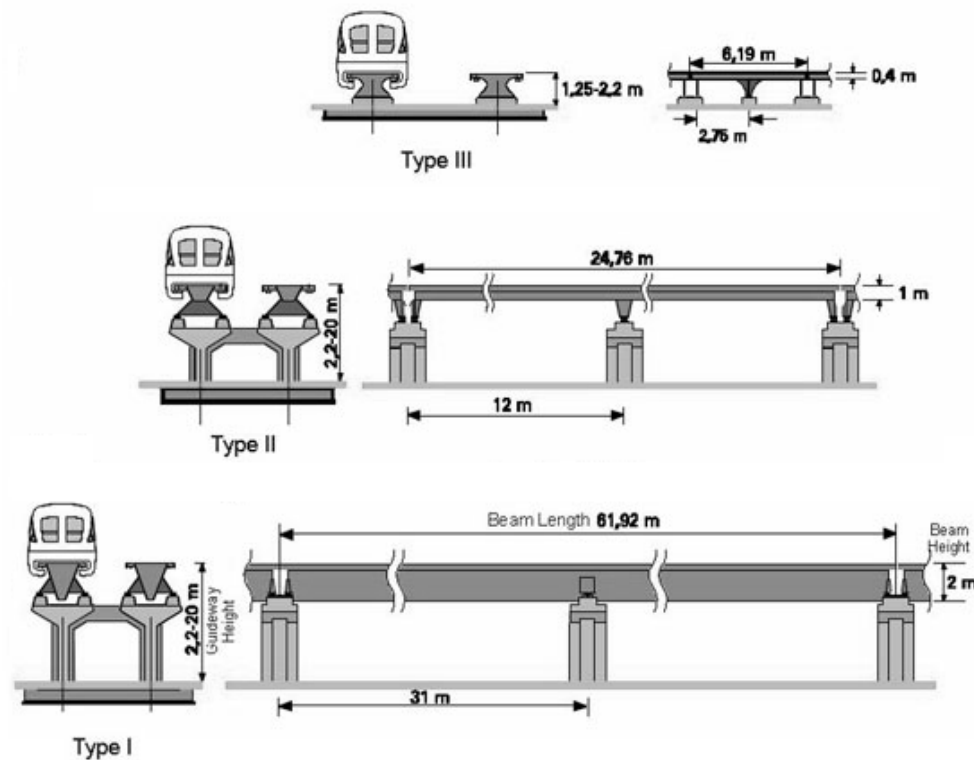


Fig. 1 Standard guideway types

III. MAGLEV STATION

Maglev stations are key regional transportation facilities designed to provide access for high volumes of passengers. Maglev stations provide regional and local intermodal connections, as well as national and international connections to passenger facilities [16]. Fundamentally, a maglev station is equivalent in planning, design, and operation to an inter-city or commuter railroad station [17]. Stations collect and distribute as many passengers as possible with a minimum amount of confusion and inconvenience. Stations should have the capacity to accommodate large concentrations of passengers at various times. Stations activities consist of everything from passenger service to the maintenance of the building. It is important to provide the traveler with a pleasant experience and atmosphere that will hopefully lead to repeat business in the future. Stations should be able to provide for all of the modern conveniences to better serve employees as well as weary travelers. The important idea is to be able to get people to their next destination as soon as possible. If a delay happens, the station should be equipped to accommodate passengers' needs. The aesthetic features of stations are intended to reflect intrinsic values of the maglev system, including advanced technology, movement, and speed. The conceptual design calls for open-air stations with natural light and ventilation.

The Fig. 2 shows the different sides of the Longyang maglev station with curved roof, in Shanghai, China. The Shanghai Maglev Train (SMT) connects the Longyang Road station (LYR), served by Metro Line 2 situated in the Pudong trade centre in Shanghai, to the Pudong International Airport (PIA). The Fig. 3 shows the interior views of the Munich main station in Germany. The German TR09 maglev train connects the Munich central railway station to the Munich International Airport Link (Franz- Josef Strauss International Airport).

In elevated guideways, all station platforms are elevated. Where it is practical, access to the platform areas will be from at-grade entrance lobbies. Where site conditions require an entirely elevated station – for example, where the station is to be constructed above an existing transportation facility – the station lobby is constructed as a mezzanine level. At mezzanine stations, pedestrian bridges provide direct access to nearby intermodal transportation facilities, parking, and transit-oriented development. Elevated platforms allow direct access through train doors without steps or ramps. No free passenger access to the guideway will be permitted, for safety reasons. This is mandatory due to the speed and low noise profile of maglev systems. The use of docks and in-station transfer switches means that passing trains, while not necessarily in close proximity to platforms, could injure anyone who strayed into the active main guideway. For vertical circulation, all maglev system stations provide escalators and elevators as the primary elements and stairs as the backup.

The Tables I and II show the components of a maglev station. The plaza level is the interface between the station and its environment. It includes intermodal facilities, potential convenience retail, and pedestrian-friendly street amenities. The station lobby may be located on the plaza level or on an elevated mezzanine. The lobby includes passenger information, ticketing, retail, restrooms, possible baggage facilities, and access to the platform level.



Fig. 2 Shanghai maglev station

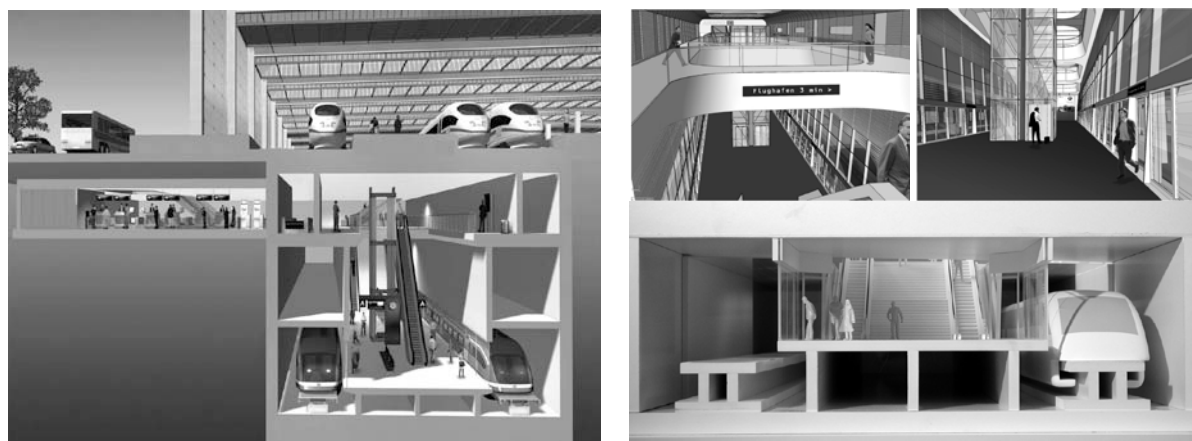


Fig. 3 Munich maglev station

TABLE I MAGLEV STATIONS COMPONENTS

Item	Goal	Including	Materials
Primary Structure	structural elements of the stations	columns and platforms	cast-in-place concrete
Station Roofs and Platform Enclosure	providing a comfortable balance of shade and natural light	columns and beams (a), exterior walls (windscreens) (b) translucent (c) and solid (d) portions	(a): steel (b, c): transparent glass or polycarbonate panels (d): metal panels with a waterproof membrane
Platform Level	- separating the maglev guideways and trains by platform doors - providing separation from arriving trains and the guideway area	floor (a), doors (b)	(a): ceramic tile flooring (b): glass
Lobby Level	- providing visibility, natural light, and ample opportunities for cross-ventilation - providing separation between the underside of the trains and occupied areas and preventing wet trains from dripping onto the lobby level of the station	lobby walls (a), exterior walls of the service rooms and retail spaces at the lobby level (b), interior walls on the lobby level (c), enclosure (d)	(a): glass, louvered glass, louvered metal, and perforated metal (b): concrete block, or cast-in-place concrete with some areas clad in tile (c): metal studs with drywall where appropriate (d): a transparent material such as glass or polycarbonate
Plaza Level	providing a hospitable pedestrian environment through the use of appropriate landscaping, sidewalk level retail businesses incorporated into parking structures, and ample pedestrian-scale lighting	potential public art installations, outdoor seating and trash receptacles, shelters for passengers waiting for arriving buses, taxis, or kiss and ride pickup.	primarily of concrete
Sustainability	reducing the energy consumption requirements of the stations through the provision of natural lighting and ventilation	no air conditioning at the platform levels	during the day: photovoltaic solar panels installed on the roofs at night: LED lighting or other high-efficiency lighting systems

TABLE II LOBBY & PLAZA AND PLATFORM LEVELS

	Including	Roles
Plaza Level	intermodal facilities	- connecting passengers with buses, taxis, and automobiles - providing separate loading zones for buses and automobiles - providing direct connections to adjacent airports or train stations - providing direct access to each station's parking facilities
	pedestrian amenities	- lessening the visual impact of the large stations and parking garages with trees and "soft" landscaping - providing a friendly and secure pedestrian environment with pedestrian-scale lighting - providing additional interest to for the station plaza area with providing public art on the plaza level
	retail	- providing a retail amenity for passengers - creating a safer and more friendly environment for passengers with the presence of pedestrian-scale retail businesses
	access to station lobby	- providing direct access to the station lobby - adjoining the plaza and lobby entrances immediately - providing access to the lobby level via pedestrian bridges
Station Lobby	information counter	at a central location that is highly visible to those entering through the station's main doors
	ticket vending machines	at convenient locations throughout the stations, including near the station entrances
	retail space	coffee shops, newsstands, and convenience stores
	access to platform level	via escalators and elevators
	restrooms	at the ends of the station lobby
	service and mechanical functions	at the ends of the station and physically separated from the passenger lobby areas
	potential baggage facilities	in the service area at one end of the maglev station
Platform Level	passenger information	providing information panels and system signage at the platform level
	seating	for riders waiting for their trains to arrive
	lighting and sun protection	- allowing natural light through to the platform level - offering screening and shaded areas to protect passengers from intense sunlight
	platform doors	preventing passengers from entering the track area
	potential baggage area	providing a secure baggage service, including a service elevator for transportation of baggage between the platform level and the lobby level of the station

The Fig. 4 shows maintenance tracks for a maglev system. The Figs. 5 and 6 show stations activities and their equipment in the maglev systems.

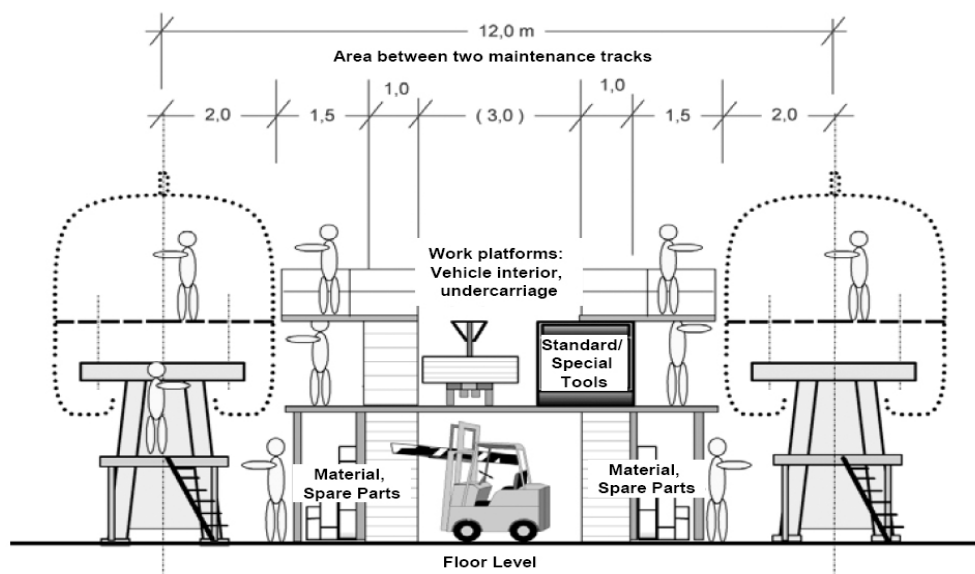


Fig. 4 Maintenance tracks

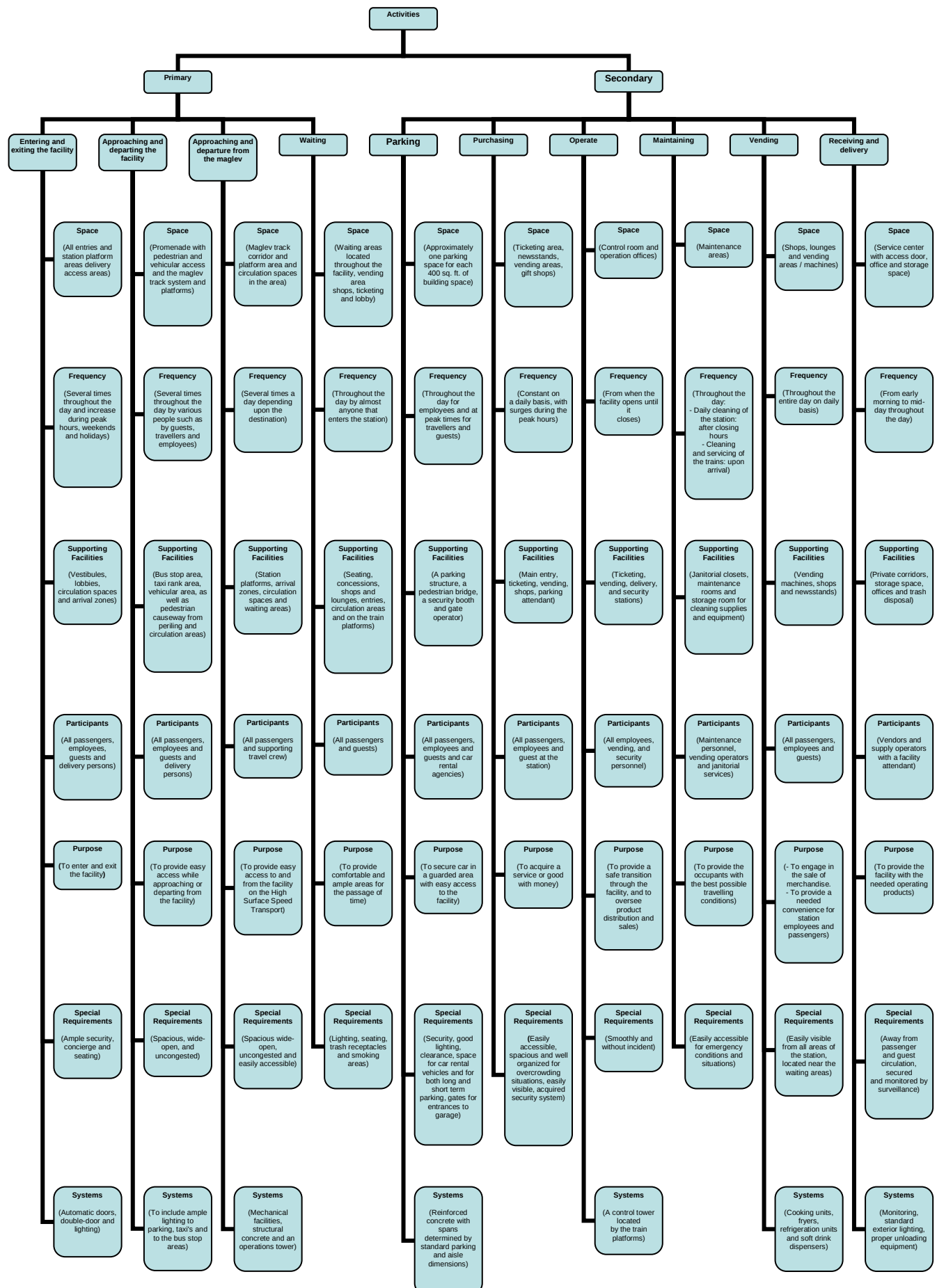
At a maglev station, primary activities include approach, arriving, entering, waiting, exiting, and departure. Secondary activities include parking, purchasing, operation, maintaining, vending and receiving. The station services, including public rest rooms, snack service, newsstand, staffed ticketing and information center, and public telephones should be provided. Stations should also provide facilities (shops, changing rooms, luggage storage, etc.), access to traveller services such as station cars, and advertising displays. All stations would feature public art appropriate to their locations. Public art is an excellent adjunct to station design and a popular feature. Train and station operations require the station personnel and security. Station managers and ticket agents control the station activities, providing passenger assistance and information as well as inspecting train sets when in station. Armed security personnel are provided at every station. Large stations have multiple security personnel, and parking garages are policed. A structure should be provided for parking and is not included in the overall square footage. The parking structure includes both short-term and long-term spaces and spaces for rental vehicles and employees.

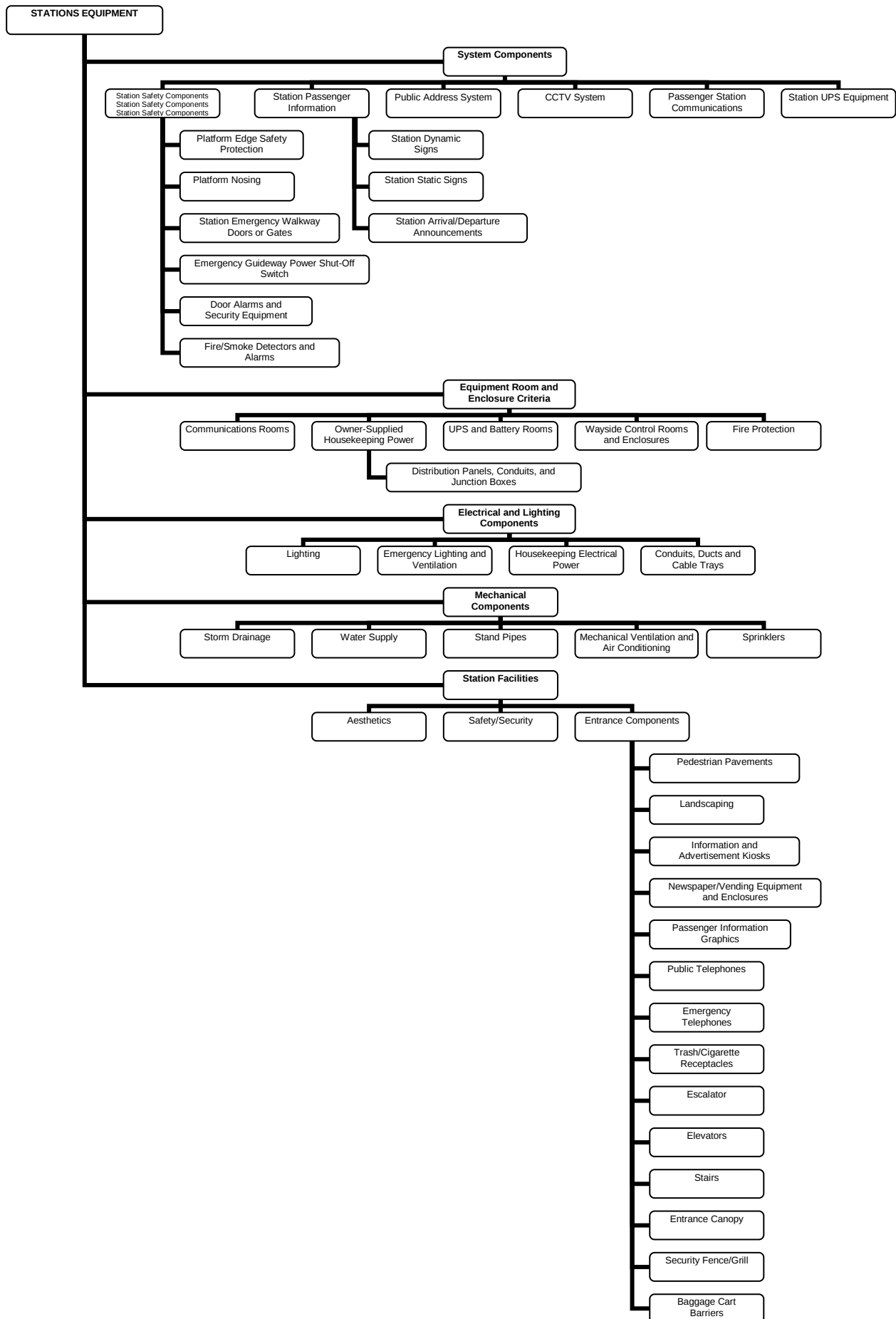
The main hall includes the baggage claim area and ticketing as well as ample waiting area for those just arriving or for those waiting to leave the station. On the other hand, guests find an interesting tall space that serves as both a lounge as well as a cafe for those waiting for their respective trains to arrive or depart. The level allows for convenient access to the train from the station or vice versa. Perhaps the most interesting aspect of a station itself is the ramping system, which is for the direct access of passengers to the train from the ground level as well as from the station. The design strategy behind the ramping system is to literally show the movement of passengers throughout the station through a transparent structure which allows for views as well as brings the outdoors into this portion of the building [18].

IV. MAINTENANCE FACILITY

Maintenance facilities facilitate routine servicing, cleaning, storage, and repair of vehicles as well as the equipment and infrastructure for the guideway maintenance along the route. The maintenance facility includes vehicle maintenance tracks, maintenance workshops, vehicle-washing facilities, parking tracks, offices, and the maglev system operations control center. The maintenance facility is where the majority of the maintenance work for the maglev system is based. It is the location of the operation control center, where the operation and dispatch of the fully automated maglev train system is controlled and monitored. The maintenance facility is also the primary location of maglev vehicle parking tracks. The activities taking place or based at the maintenance facility include scheduled maintenance measures for all maglev equipment along route, scheduled inspection, servicing, and interior cleaning of maglev vehicles, scheduled overhaul of maglev vehicles, quick exchange of maglev vehicle modules, unscheduled maintenance measures, repairs, maglev vehicle integration (re-assembly of vehicles after shipment), painting of maglev vehicles, maglev vehicle battery maintenance, parking of maglev vehicles and maintenance vehicles, vehicle washing, maintenance management for all maglev subsystems, preparation of maintenance vehicles for nightly activities, administrative and management office work, parts and equipment storage. The maintenance facility includes the activities of system operation control center, system offices, maintenance offices, maintenance workshops, spare parts storage and tracking, maglev vehicle maintenance tracks, maglev vehicle-washing tracks, outdoor maglev and/or guideway maintenance vehicle-parking tracks, guideway maintenance vehicle depots (located adjacent to one of the vehicle parking tracks).

In the maintenance facility, similar materials and roof forms cover the tracks and office/workshop areas, establishing a relationship to the family of stations. This includes the use of translucent roof materials for natural lighting, cross-ventilation to take advantage of mild weather, the metal panel system, and glazing. The overall building includes offices, workshops, and maintenance and washing tracks. Including the guideway tracks leading to the building and those for parking and access, a fenced-in area is required. The maglev vehicle maintenance tracks are grouped together in an open-style building (an open design without intermediate support columns is preferred). The maintenance tracks are elevated to allow convenient access to the underside of the maglev vehicles, with work platforms on both sides running the length of the tracks to provide access to the sides and top of the maglev vehicles. The maglev vehicle washing track is located in an adjacent bay (separated by a wall from the main building) due to the special equipment involved and the wet environment. Separate bay doors are provided for each track, as well as appropriate lighting both inside and outside of the building since much of the maintenance and cleaning work occur at night. The vehicle parking tracks have platform access on one or both sides to allow interior cleaning crews convenience access. The maintenance vehicle depot is in a separate location from the main building due to the fuelling and application requirements of these diesel vehicles.





V. DESIGN AND EVALUATION CRITERIA

There is only one technical aspect of the maglev system that constrains the design of stations: unlike railroad tracks, the maglev guideway cannot be crossed by passengers and vehicles at grade. As a result, the design of maglev stations must provide grade-separated passenger access to the station platforms. This form of access requires vertical circulation (stairs, elevators, escalators) to connect platforms with tunnels under or bridges over tracks. Stations should provide proper functions of typical transit stations, including platforms, shelter, vertical and horizontal circulation, amenities and services, climate controlled waiting room, public restrooms, snack service, public telephones, changeable message display, safety, etc. All the station designs should be planned to be consistent with the character of the buildings in the area of operation or predicated on the community standards of the local area where each station is located. The station must support the safe movement of passengers at specified flow rates and must support particular levels of the vehicle traffic. The interior of the facility should be free of as many obstructions as possible and arranged spatially on an open plan to promote a feeling of movement throughout the facility. The focus in design of stations is to introduce the notions of movement not only on the exterior, but also in the interior.

In general, the following functional requirements can apply to all maglev stations:

- Enable efficient access and movement of large volumes of passengers.
- Accommodate trains with the potential for future expansion to more trains.
- Support connections to other modes of transportation, including light rail, bus, shuttle, and taxi. In addition, allow for the option of remote airline check-in and baggage handling (possibility to be further developed in future phases dependent on resolution of all associated safety and security issues).
- Provide parking for maglev passengers.
- Provide full accessibility for disabled patrons and meet all related requirements.
- Interface with adjacent land uses including potential transit-oriented development

There are a number of key criteria for the design and evaluation of maglev stations. Some of them are listed in Table III. The criteria include main categories of engineering and environmental. Environmental issues including constraints and impacts criteria can affect the location of stations [19]. Sometimes, tunnels are situated at the stations (See Fig. 7). For aerodynamic reasons, the speed of maglev vehicles is limited in the tunnels. Taking the high velocity of the maglev vehicle and the comparatively small free cross-sectional area of the tunnels into consideration, there was a high risk of adverse aerodynamic effects for the passengers, vehicle and the tunnel structures and equipment. The Table II shows the aerodynamic issues for the design of maglev stations [20].

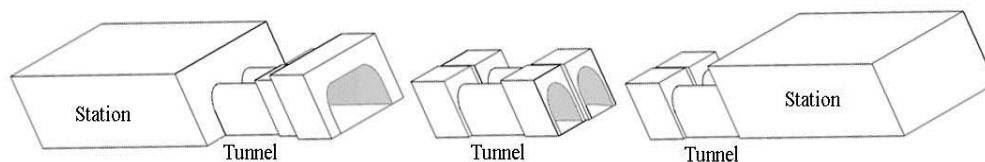


Fig. 7 Sketch of a maglev station with tunnel

TABLE III KEY CRITERIA FOR DESIGN OF MAGLEV STATIONS

Objective	Criteria
maximize ridership/revenue potential	• travel Time • length • population/employment catchment
maximize connectivity and accessibility	• intermodal connections
minimize operating and capital costs	• length • operational issues • construction issues • capital cost • right-of-way issues/cost
maximize compatibility with existing and planned development	• land use compatibility and conflicts • visual quality impacts
minimize impacts to natural resources	• water resources • floodplain impacts • threatened & endangered species impacts
minimize impacts to social and economic resources	• environmental justice impacts (demographics) • farmland impacts

minimize impacts to cultural resources	• cultural resources impacts • parks & recreation/wildlife refuge impacts
maximize avoidance of areas with geologic and soils constraints	• soils/slope constraints • seismic constraints
maximize avoidance of areas with potential hazardous materials	• hazardous materials/waste constraints
minimize public, political, and institutional conflicts	• public/political/institutional issues
land use	• land use compatibility and conflicts • visual quality impacts
natural resources	• water resources impacts • floodplain impacts • wetlands impacts • threatened & endangered species impacts
social and economic resources	• environmental justice (demographics) • community & neighbourhood impacts • farmland impacts
cultural resources	• cultural resources impacts • parks & recreation/wildlife refuge impacts
engineering and environmental constraints	• soils/slope constraints • seismic constraints • hazardous materials/waste constraints
public/institutional constraints	• public/political/institutional issues

TABLE IV AERODYNAMIC ISSUES FOR DESIGN OF MAGLEV STATIONS

Objective	Criteria
Health risk of passengers/ staff due to pressure fluctuations	$\Delta p \leq 10 \text{ kPa}$
Pressure comfort in the vehicle and in the tunnel areas including the stations	$\Delta p (\Delta t=1s) \leq 0.5 \text{ kPa}$ $\Delta p (\Delta t=3s) \leq 0.8 \text{ kPa}$ $\Delta p (\Delta t=10s) \leq 1.0 \text{ kPa}$
Micro-pressure waves at the external portals and interior portals within the stations	$\Delta p < 20 \text{ Pa}$
Air velocity related to comfort	$v_{\max} < 5 \text{ m/s}$ $v_{\text{mean}} < 3 \text{ m/s}$
Examination of the loads on the tunnel structures including the stations	$p_{\text{structure}} > p_{\text{possible}} [\text{Pa}]$

VI. LAND USE

Stations should be sited in high-visibility locations along regional freeways, and at major destinations such as airports and shopping centers. The stations will be visible to literally millions of residents and visitors. The design should express the fundamental aesthetic values of the maglev system. Maglev is a sophisticated surface transportation technology. Stations are designed to express the technological sophistication of the system using materials, lighting, and form. The maglev system should offer unprecedented ease of movement. Stations should be designed for quick and convenient movement of passengers through the station facilities and into the train boarding areas.

The placement of stations determines based on ridership, system needs, local planning, and environmental constraints/conditions. The specific features and amenities depend on the passenger demand and station type. Several factors must be considered in the identification of stations along the system, including maintain, speed, cost, ridership, operating and maintenance costs, travel time, population and destinations [19]. The principal design criteria include the safety and fire protection/prevention, materials, structures and colours of walls, ceilings and floors, lighting, etc [21]. Stations are generally spaced following the pattern of urban centers.

Stations serve as the only point of access or connection to high-speed trains systems. The selection of station locations is one of the key considerations that will affect the relative effectiveness and efficiency of the high-speed train service. The number of and spacing between stations and local access to these sites are critical to the trade-off between system accessibility to riders and line haul travel time. The location of stations with respect to travel markets and transportation infrastructure, the ease and availability of intermodal access to and from the station, and the travel time to and from the station can be critical determinants of system performance. Spaces are provided within the station for ticket sales, passenger information, station administration, baggage handling, and a reasonable amount of commercial space for newsstands, restaurants, etc. The different unit costs account for differences in station size, configuration, and general location. These costs are assumed a rough average, since station costs are expected to vary widely at specific locations.

The site and parking include the paving, parking structures, and landscaping of the site around the passenger station building. Also included is the provision of street and roadway modifications necessary to provide access to the site. Land use

compatibility and conflicts include consideration of proximity impacts on adjacent land uses, such as noise, vibration, and visual impacts along segments and traffic and air quality impacts at stations. Potential land use conflicts may arise from siting stations within residential areas, near schools, and adjacent to parks and recreational areas among others. For this evaluation, stations are considered to include the station, platforms, parking facilities, and ancillary facilities. Identify if the location of a station would lead to conversion of adjacent land uses that would be incompatible with general plan land uses (e.g., conversion to commercial uses in areas not planned for such uses). It should be assumed that commercial development would be induced near stations. This should be evaluated against the general plans and other policy documents to identify incompatibility. Community and neighbourhood impacts include disruption to neighbourhoods and physical barriers or divisions of established communities that would affect those who live or work in the area. If segments lie within a new corridor, then field review would be required to identify areas that may be divided or separated from other parts of the neighbourhood or community. Also, note if there is the potential to affect community resources or activity centers. Community resources can include police and fire stations, libraries, hospitals, recreational facilities, churches, neighbourhood shopping areas, schools, and beaches, among others. Public, political, and institutional issues that may affect the siting of location of stations need to be considered early in the planning process and documented in the regional station evaluation. The Figs. 8-10 show the Shanghai and Munich maglev routes. In Fig. 9, the roof building at the south is the maglev station, and the square building on the north is LYR.



Fig. 8 Shanghai maglev train (SMT) route



Fig. 9 Shanghai maglev station

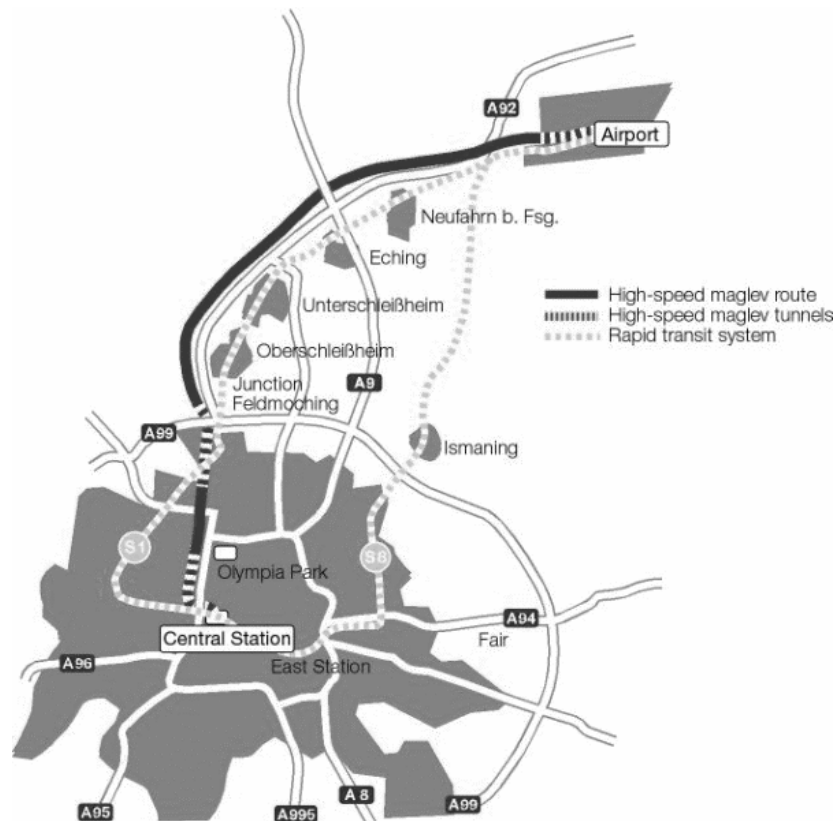


Fig. 10 Munich maglev line

VII. CONCLUSIONS

Maglev stations are centers for planning, traffic attraction, and preparing the fleet. They definitely play a very important and influential key role in any maglev system. The efficiency of maglev systems over the national and regional development depends on stations. The development hub of maglev systems mainly formed around the stations. Stations have emerged as a new central place in metropolitan cities. They have become hub of networks due to their high accessibility by different modes of transport in high scale level.

Maglev is a high-tech transit system. Therefore, its stations should be designed to express the technological sophistication of the system. The design of station should be consistent with buildings character in the area of operation or predicated on community standards of the local area where the station is located. The design should express fundamental aesthetic values of the maglev system. Aesthetic features of the station should reflect intrinsic values of the maglev system, including advanced technology, movement, and speed.

The specific features and amenities depend on the passenger demand and station type. The station must support the safe movement of passengers and particular levels of the vehicle traffic. Stations should have the capacity to accommodate large concentrations of passengers at various times. Stations should be able to provide for all of the modern conveniences to better serve employees as well as travelers.

The selection of station location is one of the key considerations that affect the effectiveness and efficiency of the maglev system. The location of the stations can be critical determinants of system performance. Several factors must be considered in the identification of stations along the system, including maintain, speed, cost, ridership, operating and maintenance costs, travel time, population and destinations. The station placement determines based on ridership, system needs, local planning, and environmental constraints/conditions.

Stations should be spaced following the pattern of urban centers. The area required for the station should be calculated based on the levels of economic, industrial, commercial, political, and cultural in the region. It should be assumed that commercial development would be induced near stations. This should be evaluated against the general plans and other policy documents to identify incompatibility. Public, political, and institutional issues that may affect the siting of location of stations need to be considered early in the planning process and documented in the regional station evaluation.

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