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Revolutionizing Urban Transit? On the Potential and Pitfalls of Maglev Systems

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ABSTRACT

Maglev technology offers significant advantages for urban passenger transportation, including reduced noise pollution and zero particulate emissions, making it particularly valuable in densely populated areas. However, challenges such as high capital costs remain substantial. Medium-speed maglev systems hold the greatest potential in applications like urban ring lines, airport links, and routes through topographically challenging areas. For short-distance urban transport, traditional systems like trams and buses are still more practical and cost-effective. A key concern is the aesthetic design of maglev guideways, as their current brute, concrete appearance makes them unappealing for broader market adoption. While cost, design, and infrastructure challenges currently limit the widespread use of urban maglev, its potential to enhance urban mobility remains significant.

Keywords: Disruption; Barriers to Acceptance; Infrastructure Design; Environment, Urban Planning, Mobility Challenges, Cost-Benefit.

Introduction

Maglev systems, which are based on magnetic levitation technology and linear motors, are used in urban and regional transportation for medium-speed applications. These systems compete with conventional transportation systems based on traditional wheel-rail technologies, such as commuter trains, regional trains, subways, trams, and buses.

One of the most well-known maglev systems is the Linimo system (Tobu Kyuryo Line) in Japan's Aichi Prefecture, which has been in operation since 2005 and reaches a top speed of around 100 km/h. Another system is South Korea's Incheon Airport Maglev, which opened in 2016 and connects the airport to Yongyu Station, reaching a maximum speed of around 80 km/h [14]. In China, several medium-speed maglev systems are either operational or planned. The Changsha Maglev Express, which has connected Changsha Huanghua Airport with the city center since 2016, reaches a top speed of about 100 km/h [13]. The Beijing S1 line, which opened in 2017, connects the western suburb of Mentougou with Beijing’s central area and operates at similar speeds. Further planned systems in China include the Fenghuang Maglev in Hunan Province, which will link Tongren Airport to Fenghuang, and the Qingyuan Maglev in Guangdong Province, which serves as a pilot project and is also expected to reach approximately 100 km/h [8][17]. In the Russian Federation, several research projects are underway [18], including the Moscow Monorail, which is powered by linear motors [4][16].

An important project in Europe is the TSB Bögl, which is currently in the advanced development and testing phase. This system is designed for various urban and regional applications and is expected to reach a top speed of about 170 km/h, with potential future speeds of up to 200 km/h. The project is being further developed in close collaboration between the German company and the People’s Republic of China, where a test track is also located. In Europe, the company is working toward approval from the German Federal Railway

Authority (Eisenbahnbundesamt) and seeking routes for passenger or freight transport applications [2]. A feasibility study has been conducted for Munich Airport, but further plans have not been disclosed. In 2024, there was also a proposal for a short inner-city route in Nuremberg, which is still under discussion.

Maglev systems for medium speeds are typically designed for passenger transport and, as of 2024, are still rarely considered for freight transport.

Suitability from a systems engineering perspective

From a technical standpoint, urban maglev systems offer several advantages, but they also have certain drawbacks. Due to their levitating operation without mechanical contact, maglev systems are significantly quieter at the same speed compared to conventional wheel-rail systems, thereby reducing noise pollution in urban areas. Additionally, operating costs can be lower because of the minimal mechanical wear and tear [15].

Maglev systems are expected to provide high operational reliability, as they are less susceptible to weather-related disruptions and, for example, are scarcely affected by sand particles in desert regions such as the Arab countries. Another advantage is the flexibility in route design, as maglev systems can handle steep gradients and sharp curves much more efficiently than conventional driverless transit systems [7]. Particularly noteworthy is that maglev systems do not produce particulate matter emissions, as there is no mechanical abrasion between the vehicle and the guideway [11].

The initial investments for constructing elevated or tunneled infrastructure and acquiring Maglev trains are significantly higher than for tram and bus systems. Also, there are conflicting reports and inconsistent calculations regarding the energy requirements of various maglev technologies. It is generally assumed that the energy consumption of the vehicles during operation is not significantly different from conventional systems [3]. However, additional costs are incurred for the operation and maintenance of the complex control, sensor, and regulation systems in maglev systems.

Suitability from an urban planning perspective

The use of maglev systems in urban and regional transportation in Europe requires careful consideration of many other factors. Therefore, in addition to the above-mentioned typical technological system characteristics, the following sections discuss some aspects that are particularly relevant for passenger transportation in metropolitan areas.

When it comes to making cities future-proof, the task of urban planning is, first, to provide as many people as possible with affordable mobility and, second, to ensure mobility especially for those groups of people who, at the beginning and end stages of life, experience physical limitations and have fewer mobility options. This includes children, the elderly, and all individuals with limited mobility or disabilities—parents with children are also part of this group. Future-oriented urban planning is thus not only aimed at providing sufficient transport capacity for everyone, but the transportation systems must be specifically tailored to the needs of the most vulnerable and those who require support [10]. Accordingly, a high degree of comfort and safety is fundamentally required.

Since mobility by car or bicycle is only feasible for people within certain age groups, it remains essential to prioritize mobility and urban planning efforts on promoting transportation systems that can guarantee the best long-term and sustainable mobility options for all citizens, regardless of whether they are young or old, healthy or physically impaired. These modes of transportation are walking and public transportation: Only these forms of mobility can safely and quickly transport all citizens at any time, regardless of their life stage or whether they can walk independently or require a wheelchair or other forms of assistance. Therefore, pedestrian traffic and public transit should take absolute priority in future-oriented urban mobility planning.

Transportation systems that require underground or elevated tracks and stations with stairs, escalators, and elevators are, under these circumstances, rarely the preferred option. Subways and elevated trains, as well as maglev systems, can, due to their access-intensive and segregated infrastructure, sometimes even pose a barrier to local mobility. This leads to the conclusion that for sustainable cities, the proportion of underground or elevated public transportation infrastructure in urban areas should be limited to specific, sensible applications. This also applies to maglev systems, although they have significant advantages in terms of noise and particulate pollution when operating in urban areas. Instead, systems that can be seamlessly integrated into the regular street network, such as trams and sometimes bus systems, are sometimes more beneficial to the public.

Even in situations where a separate transportation infrastructure is sensible and necessary (such as for commuter trains, subways, or potentially maglev systems), new infrastructure projects often face significant resistance from the public. At least in Europe, there seems to be a widespread belief that elevated transportation infrastructure is always disruptive in metropolitan areas, even though there are numerous urban settings where such structures can positively contribute to the cityscape. Vienna is known for its elevated Art Nouveau subway lines. In central Berlin, the elevated public transport lines between Ostbahnhof and Charlottenburg shape the cityscape. Wuppertal would hardly be famous without its iconic suspension railway. In Paris, many Metro and RER lines run on impressive viaducts, creating an attractive and interesting urban landscape.

This demonstrates that sophisticated architecture and good design can have a substantial impact on public acceptance of transportation infrastructure in urban areas, while poor design can have the opposite effect. It is precisely the concrete viaducts of monorails, commuter trains, and maglev systems, which have mostly been designed based on purely functional criteria, that display significant aesthetic shortcomings, making public acceptance more difficult. It’s hardly an exaggeration to describe the design of well-known monorail and maglev track systems as bulky and uninspired. Is it any surprise that reservations about new technologies like maglev are heightened when so little effort is made to meet even minimal aesthetic standards for infrastructure design?

Many European, Russian, and South American cities are characterized by historically significant urban areas that not only shape the city’s international image but also contribute to the regional identity of their citizens. The comprehensive preservation and protection of these areas are central priorities in responsible urban planning. While streetcars and buses can be integrated relatively harmoniously into the cityscape, the routing of elevated transportation infrastructure often requires massive structures that are visually and structurally disruptive. Elaborate structures for stations, escalators and elevators make it difficult to integrate suburban trains, monorails and even maglev systems into the cityscape.

For example, when evaluating a suburban rail connector for Nuremberg, Erlangen, and Herzogenaurach (Germany), it was determined that an elevated route through the city centers should be avoided due to a potential monumentality of the tracks and the likely massive size of the stations [9]. This highlights once again that, when it comes to innovating new transportation systems, citizens and city governments often place significant importance on the visual, aesthetic, and ecological impact of new public transportation infrastructure.

Ongoing competition between transportation systems in public spaces

Urban space is both limited and highly valuable, and its use is subject to the competing demands of various forms of mobility [5]. Transportation planning in cities is often shaped by different interests, many of which strongly advocate for the continued prioritization of private motor vehicle traffic.

In efforts to preserve or even expand space for cars, costly detours and alternative infrastructure for public transit are often pushed for. Planners who yield to this pressure typically design public transit systems to go underground (subways) or be elevated (+1 level systems like light rail, monorails, urban cable cars, and maglev systems). Simply put, the more urban space is allocated to motor vehicles (parking lots and roads), the more public transit is pushed into tunnels or elevated tracks.

Well-known international examples of decisions favoring car traffic over public transit in recent decades include cities like Bangkok, Beijing, Shanghai, Seoul, and Moscow, where the dominance of car traffic has forced public transportation infrastructure either underground or elevated. Likewise, the construction of elevated urban maglev infrastructure often reflects a setback in the competition for space and mobility rights.

The burden of this encroachment falls primarily on three groups: public transit riders, transit operators, and city residents without access to private vehicles.

- Public transit users are likely to experience significantly longer travel times and more difficult access due to the encroachment of private vehicle traffic. Elderly people, in particular, face increased physical strain, higher risks, and reduced safety. Comfort decreases, while the effort, cost, and time required for mobility increase.
- Public transit operators are confronted with much higher investment and operating costs. They bear the financial burden of displacement caused by cars. These high costs lead to delays or even the questioning of expanding public transit infrastructure. From the operators' perspective, more complex systems like maglev trains, commuter rail, or subways are primarily practical for heavily used, longer routes in metropolitan areas.
- Urban residents face ecological and economic consequences. Increased daily transportation costs and negative environmental developments reduce the long-term sustainability of the entire metropolitan area.

In summary, the long-term interest of a metropolitan area is to ensure that daily and local mobility is as affordable, straightforward, and convenient as possible. Shifting public transit underground or onto elevated tracks generally contradicts this interest. Consequently, urban maglev systems have only limited use cases in cities: since they traverse space on elevated structures, they are typically suited only for longer inner-city routes. Compared to trams, maglev systems are less suitable for short-distance, local mobility. Maglev systems, on the other hand, become attractive for longer urban connections where relatively high transport speeds can more than compensate for time losses due to longer access times to stations and greater distances between stops. Such potentially useful applications for urban maglev systems in passenger transport include urban ring lines in large cities, airport connectors, or routes with challenging topography that cannot be efficiently served by buses or trams.

On the Distorted Picture of Energy Demands and Operating Costs

A significant portion of the operating costs for public transportation systems is driven by their energy consumption. As with high-speed rail systems (such as the ICE, TGV, or Transrapid), private operators of local transit systems rarely provide reliable data on their actual energy usage. The values reported in the literature are often unsuitable for scientific comparison because the methods of calculation are typically not disclosed. In particular, the metric of energy consumption per seat-kilometer/mile and speed has proven highly susceptible to manipulation [3]. Additionally, it is usually unclear whether the energy consumption of auxiliary systems, such as air conditioning or heating, is included in system comparisons, further obscuring the data. This calls for a more fundamental and alternative analysis.

There is a general consensus within the industry that maglev systems in local transit (such as Linimo, Rotem, TSB, etc.) consume approximately the same amount of energy during vehicle operation at comparable speeds as trams or subway trains. In terms of pure vehicle operation, the energy demands of these systems likely do not differ significantly. Energetic advantages (or disadvantages) for urban maglev systems or monorails in regional transit have not yet been credibly demonstrated. However, urban maglev systems have the capability to achieve higher travel speeds, which would naturally result in increased energy consumption.

When examining other operational costs, significant differences become apparent. Trams that operate on streets require minimal additional infrastructure for lighting or access, whereas maglev systems, monorails, and all elevated rail systems necessitate additional accompanying infrastructure with considerable energy demands. These include escalators, elevators, lighting, ventilation, and enhanced security systems. These system-specific requirements add to the overall energy consumption of vehicle operation. As a result, elevated and underground public transit systems typically have significantly higher energy demands due to the needs of their accompanying infrastructure. From an energy consumption standpoint alone, well-established modern tram systems are likely more efficient and, in many cases, preferable to urban maglev, subway, or monorail systems.

Furthermore, elevated or underground public transportation systems incur substantially higher operational costs due to the need for additional security measures (such as cameras and security personnel), infrastructure maintenance (tunnels or elevated tracks), massive air conditioning, and cleaning. These costs are considerably lower for trams or buses.

Suitability from the Perspective of the Transportation Industry

In the summer of 2022, the International Maglev Board conducted a scientific study on maglev systems. The key research question was: "To what extent are urban maglev systems suitable and practical from the perspective of the transportation industry?" The web-based survey reached over 13,000 professionals in the transportation sector [6].

The survey results show that 54% of respondents believe urban maglev systems are suitable for both passenger and freight transportation. Twenty-three percent consider them suitable for passenger transportation only, while only 4% view them as suitable for freight transportation only. Nineteen percent of respondents see no viable application for maglev systems at all.

Notably, the use of maglev as an airport link between cities and airports received strong support, with 79% of respondents in favor. Sixty-eight percent see its potential as a terminal shuttle at airports, and approximately 61% recognize its usefulness in urban or regional transportation.

When compared to other local and regional transportation modes, urban maglev systems are viewed from a different perspective. Due to their contactless technology, they score significantly better in terms of noise emissions and ride smoothness. They achieve average ratings for transportation capacity. Maglev systems also offer significant advantages in terms of particulate emissions, as they do not produce such emissions during operation. While maglev systems have a greater visual impact on the urban landscape compared to buses, trams, or subways, they are seen as comparable to commuter trains in this respect. The overall positive assessment of maglev systems by the transportation industry is based on their environmental friendliness during operation, anticipated lower operating costs, and higher passenger comfort.

These findings align with the results of a comprehensive study of the maglev industry conducted in 2018 [12].

Narrowing Down Suitable Applications for Urban Maglev Systems

The foundation of an efficient public transportation system in large cities typically begins with tram networks operating on dedicated tracks. These systems are highly effective, providing fast and reliable service for local, daily short-distance travel needs. It is only when addressing medium-distance travel demands that transportation systems using elevated or tunneled guideways become necessary. These systems can be based on either conventional rail-wheel technology or the more modern maglev technology. Especially in fully automated operation and from an environmental perspective (noise and particulate emissions), maglev systems appear to offer significant operational advantages.

Key applications for maglev systems include urban ring lines, as well as point-to-point connections like airport links, which connect airports to urban centers. In some cases, maglev systems may also serve as a viable alternative to traditional underground metro systems [19]. However, as shown, maglev systems are generally less suitable for public transportation over short distances where priority tram and bus networks are more efficient. For these shorter trips, the advantages of maglev technology, such as low noise and zero particulate emissions, are unlikely to outweigh the substantial infrastructure and construction costs when compared to tram or light rail systems.

While urban maglev systems hold potential in specific niche applications — particularly for ring lines (inner-city loops) and specialized connections like airport links — they are less practical for short-distance urban transportation, where traditional tram and bus systems remain the more efficient and cost-effective solution.

As of 2024, no recent feasibility studies have emerged regarding the use of maglev systems for container transport in cities. However, there are early conceptual proposals for the automated use of maglev technology in container ports, including the Ports of Los Angeles, St. Petersburg, and Hamburg (TSB System).

Conclusion

Medium Speed Maglev technologies offer significant advantages for passenger transportation, including reduced noise pollution and particulate emissions, making them especially valuable in densely populated urban areas. In certain metropolitan applications, maglev systems hold considerable potential, particularly for medium-speed ring lines, airport connections, and routes through topographically challenging areas. In these scenarios, maglev systems primarily compete with conventional commuter trains and subways, which remain subject to wear and tear. In other urban contexts, traditional transit systems like trams and buses often prove to be more practical and cost-effective alternatives to maglev, commuter trains, and subways.

One of the most pressing challenges for meaningfully advancing maglev systems in urban environments is significantly improving the aesthetic appeal of their guideways. If the guideways and pillars remain in their current, brute concrete form, they will render urban maglev systems entirely unmarketable and unacceptable for serious market adoption. Without a sophisticated redesign that convincingly addresses key aesthetic considerations, these systems are likely to face outright rejection from both city planners and the public.

Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

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