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Review

A Critical Review of the Proposed Hyperloop (Ultra-High-Speed Rail) Project between Mumbai and Pune and Its Broader Implications for Sustainable Mobility in Indian Cities

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Abstract: This review paper examines the appropriateness of a hyperloop line between Mumbai and Pune in India, examining, in particular, its potential economic implications and impact on people. This assessment builds on an earlier in-depth examination by the authors of the key urban and transport planning, technical, environmental, economic and human factors surrounding the hyperloop technology. The current detailed analysis of hyperloop's expected implications in the Mumbai to Pune corridor is based upon use of a wide variety of existing indicative data from many sources, which are sufficient to provide a very broad "first-step" reality testing of hyperloop's suitability to India. It could be argued that this is precisely the kind of analysis that should have been conducted, or at least made public, prior to committing to hyperloop in India. The paper highlights many negatives concerning hyperloop's construction and operation, including a very high capital cost compared to other needed urban transport infrastructure projects in India, a potential lack of patronage due to a range of factors and its potentially exclusive upper income patronage cohort. It is concluded that rather than making a costly mistake, India should address current urban mobility challenges and needs such as bus rapid transit (BRT) and metros in its innumerable cities, whose construction costs are vastly lower than the expected cost of a single hyperloop line. Technology, such as the hyperloop, would need time to mature and gain operational experience. Should any corridor be found suitable, there would still need to be a thorough, detailed benefit–cost analysis together with a dedicated examination of the technology's broader urban planning implications and less tangible factors. Setting aside the ultimate worthiness of hyperloops, India would need to at least achieve certain preconditions before proposing or pursuing such systems in the country.

Keywords: hyperloop; ultra-high-speed rail; Mumbai–Pune corridor; multi-criteria critical assessment; benefits/costs; funding

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1. Introduction and Background

Several companies are competing to construct the world's first functional hyperloop system [1]. Companies have selected corridors in several countries for their proposals. These countries include the USA, the UK, Canada, Sweden, United Arab Emirates, Saudi Arabia, Russia, France, China, Mexico, Finland and India. Researchers suggest that since this technology is new, it would be easier to select corridors for demonstration and test runs in regions that pose the least technical and geographical challenges. For instance, corridors with flat surfaces would pose fewer geographic challenges than regions with uneven geography [2]. Also, hyperloop tracks stretching over long distances would benefit cities with large populations compared to less populated cities. Heavily populated, dense cities pose more urban planning, transport and human challenges such as uprooting existing infrastructure, complex regulatory hurdles and rights-of-way issues. Such challenges in these kinds of cities will help better understand this new mode of transport's impact on cities more than in cities that pose fewer challenges [3]. Therefore, it is vital to analyse the implications of hyperloop in countries with large populations and such densely and heavily populated cities. This makes the proposed Mumbai to Pune route in India an interesting one to study. Even though the government has relatively recently approved the hyperloop (July 2019), there is no concrete study on its actual impact on the people, planning, transportation and economics in each city. This review paper, therefore, helps to fill a knowledge gap surrounding the Mumbai–Pune hyperloop corridor. It does so by investigating hyperloop's potential economic implications and highlighting its multi-faceted challenges.

Specifically, an investigation of some of the significant aspects of the proposed corridor, including station areas, existing intercity connections and the current travel behaviour between the two cities, aids in comparing the projected cost of the Mumbai to Pune hyperloop with a range of other public transport modes such as rail (Metro) and BRT projects within some selected Indian cities. This includes a range of cost, capacity and affordability factors. It highlights the potentially large impact of the hyperloop's projected costs on the funding of urgent urban mobility needs in India, concluding with a summary of the various challenges of the Mumbai to Pune hyperloop. This analysis also helps to establish certain critical preconditions that would need to be met in India for it to even contemplate any hyperloop corridor.

The specific questions which this review paper seeks to gain insights into are:

(1) Why was the Mumbai to Pune corridor chosen for hyperloop compared to other potential corridors in India? What are hyperloop's challenges and opportunities in the Mumbai to Pune corridor?
(2) Based on the best available information, what are the possible positive and negative effects of hyperloop's development in this corridor?
(3) What are the pre-conditions that may lead to positive development of hyperloop in India?
(4) How can transport planning, as well as urban and regional planning, respond to the projected effects of a hyperloop between Mumbai and Pune, considering the very specific nature of the local context?

To answer these questions, the Mumbai to Pune corridor is examined as a case study for applying hyperloop. The case study is discussed in relation to the findings from the more general review of hyperloop by the authors [4] and the specific lessons for the corridor that can be drawn from these analyses. The paper concludes with summary answers to the above four questions. The review helps to fill a knowledge gap in how to help generically assess hyperloop as a form of passenger transportation in the absence of any functioning commercial service.

1.1. Methodology of the Review

This paper did not generate any new primary data but relied entirely on information that could be obtained from academic literature and other sources available online. The information can be summarised as follows:

- Target area of the study, the importance of the Mumbai to Pune intercity connection and the cost of the proposed hyperloop;
- Perceived importance of the Mumbai to Pune hyperloop, the existing modal share for travel along the corridor and the possible shift of passengers from the existing modes of travel to the hyperloop;
- Economic impact of the Mumbai to Pune hyperloop on the funding of other urgent mobility needs in Indian cities such as BRT and metros;
- The Mumbai to Pune hyperloop case study is evaluated in terms of physical, economic, human, technical and environmental factors. It further discusses its potential urban planning and transport implications, relying mainly on known experiences with high-speed rail (HSR). The above-mentioned factors were already detailed in Premsagar and

Kenworthy's [4] paper entitled 'A Critical Review of Hyperloop (Ultra-High-Speed Rail) Technology: Urban and Transport Planning, Technical, Environmental, Economic and Human Considerations'. This information was used to assess hyperloop's potential application to the Mumbai to Pune corridor based on its publicly available existing specifications;

- The research concludes with lessons for the intercity connection between Mumbai and Pune, important preconditions for any hyperloop solution, and alternative potential solutions to improve the connection.

The above information gleaned from the academic literature and websites was analysed for its factual content and informed professional opinions and integrated into the overall arguments that have been developed in the paper about the likely performance of a hyperloop between Mumbai and Pune. Furthermore, relevant quantitative data found in the literature and elsewhere have been extracted and presented as descriptive statistical analyses at a variety of points in the paper to further support the overall views and conclusions portrayed in this critical review. In particular, such quantitative/statistical data have been used to assess possible patronage levels for the proposed hyperloop line and how the Indian government's possible contribution to hyperloop's capital costs might limit the existing availability of funds for other urgent public transport needs in Indian cities. We have also used such quantitative information to suggest how much extra high-capacity BRT and Metro might be constructed from the projected cost of the hyperloop line.

Before commencing with the case study, it is necessary to briefly summarise the findings of our more general assessment of hyperloop technology. This provides the needed groundwork to better understand the technology and its potential strengths and weaknesses [4].

1.2. Hyperloop Technology: A Brief Critical Overview

Tables 1–4 summarise the main findings of our more general review of hyperloop technology [4]. They show hyperloop's claimed characteristics alongside the expected implications of hyperloop's possible future urban and regional development and transport policy impacts. These expected implications are based on the experience of conventional high-speed rail due to lack of any commercial hyperloop lines to date.

The information in Tables 1–4 demonstrates that there are many commercial claims about hyperloop on a variety of different factors. However, for each one of these claims, there are varied counterclaims based on detailed and perhaps more objective and independent analyses. Some of these inferred results are based upon extensive studies of conventional high-speed rail, which are assumed here to be comparable to hyperloop's effects.

Overall, the review suggests that the realistic behaviour of a hyperloop service, will, according to the best available relevant information, probably contradict many of its commercial claims and likely not be of benefit to major portions of any population.

The in-depth examination by the authors in their general review of hyperloop technology also discusses a more critical comparative analysis between HSR, maglevs and hyperloop. Listed below are four key comparisons [4].

1. Hyperloop has the maximum design speed (1200 km/h) and the lowest seating capacity (28) as compared to HSR (600 km/h, 1500) and Maglev (600 km/h, 824);
2. At its current stage, hyperloop has a lot of technical issues. Additionally, the system's design and speed make it not only uncomfortable, but also potentially dangerous, whereas HSR and Maglevs have proved to be safe and comfortable;
3. The likely fare for hyperloop would be high (similar to flights) compared to HSR and Maglevs;
4. Hyperloop would operate in a near vacuum, electrically powered through renewable energy making it more energy efficient compared to HSR (electrically powered) and maglevs (electrically powered, frictionless).

Table 1. Hyperloop compared to other HSR, its corridor selection, corridor and terminals, travel time, capacity and efficiency.

	Hyperloop's Commercial Claims	Hyperloop's More Realistic and Expected Implications
Hyperloop compared to other operational high-speed ground transportation (HSR and maglevs).	Hyperloop claims to be superior to other HS ground transportation (operational, economic, environmental and social performance).	Compared to HSR and maglevs, hyperloop will have: - Higher speed; - High reliability regardless of weather conditions; - Higher fares; - Higher energy efficiency; - Lower comfort and safety.
Criteria for the selection of a hyperloop corridor		Hyperloop should connect two important growing cities of the same megaregion (minimum 500–800 km apart) with: - High economic productivity; - Important intercity connection; - Existing low interconnections with inefficient transportation modes; - Political and economic support; - A flat and straight alignment.
Corridor and terminals	Hyperloop is a guided transportation mode with a specific infrastructure along the route it covers.	- Using existing transportation infrastructure minimises total land requirement for new infrastructure, whereas land used for new infrastructure creates opportunity costs. - Hyperloop corridor would be mostly elevated on pillars 30 m apart. - It will be challenging to incorporate too sharp turns on the hyperloop corridor, lowering its flexibility. Rapid changes in the land use patterns will be visible in hyperloop regions such as: - Accelerated urban development; - Reconstruction of the urban hierarchy; - Hyperloop terminals may lie anywhere between the centre of city and its outskirts.
Travel time, travel capacity and efficiency	Hyperloop claims to be: - More energy efficient; - Having a lower station-to-station travel time (due to higher frequency between pods) than flights and transnational rail. - Hyperloop will meet the demand of 840 passengers during off-peak hours and 3360 passengers during peak hours (headway of 30 s).	- Hyperloop travel time will be like air travel, undermining the overall speed advantage and increasing journey time. - Terminals within the city centre will be more accessible due to the central location and existing access options. - Hyperloop will run for 19 h and use 5 h for maintenance. - A single pod can hold only up to 28 passengers. - The headway between pods is unrealistic and questionable due to safety reasons at such high-speed (headway of 80 s seems more realistic hence reduced capacity).

Source: [2,4–7].

Table 2. Hyperloop's energy and emissions, construction and operational costs, affordability, equity, lifestyle, safety and comfort.

	Hyperloop's Commercial Claims	Hyperloop's More Realistic and Expected Implications
Energy consumption and emissions of greenhouse gases	- Low energy design, self- sustaining and cost-effective (powered by solar energy, 2–3 times more energy-efficient than HSR). - Hyperloop will be able to provide more energy than required to operate, which may be stored and utilised to operate the system in cloudy weather, at night or in the tunnels.	- The way to power the system will differ depending on system requirements and terrains. - Climate and altitude limitations, mean powering hyperloop through solar energy is possible only with abundant sunlight. - It may be more efficient and cheaper to power hyperloop by generating renewable energy (solar, wind, water) depending on the region, altitude and climate. - High indirect emissions due to embodied energy.
Construction and operational costs	- Low cost of construction and operation.	- Underestimated cost of construction, actual real-life costs of hyperloop are very likely much higher than anticipated. - Some essential costs such as overrunning costs plus operating and maintenance costs need to be considered.
Affordability, equity and impact on lifestyle	- Hyperloop will be affordable to a large portion of the population.	- Hyperloop is likely to have fares similar or higher than flights. - Hyperloop will be more relevant to the premium passenger market and likely affordable only to the rich, causing more societal inequity. - Hyperloop will consume investment funds that could otherwise be used to develop other cheaper public mobility infrastructures. - Possible loss of public goodwill and political capital. - Station areas may be transformed into higher-income enclaves, causing gentrification.
Safety and comfort	- Hyperloop's design indicates it is safer compared to planes and trains.	- Hyperloop will consist of windowless pods running in a protective tube which will block any interaction with its immediate environment and likely cause claustrophobia with some passengers. - Small headway between pods may cause life-threatening concerns. - At such high speed, passengers may feel the vibration and jostle. Also, the slightest deviation of the rail could cause discomfort and fear. - Huge curves would be required to prevent breaking speed and motion sickness, thus increasing costs. - Digital live solutions would be used in the windowless pods to replace direct views of nature.

Source: [2,4,5,8–11].

Table 3. Hyperloop's environmental effects and regional spatial development effects.

	Hyperloop's Commercial Claims	Hyperloop's More Realistic and Expected Implications
Environment	- Hyperloop promises a countering effect on the increasing automobiles and air travel, reducing roadway congestion, fuel consumption and GHG emissions.	- Hyperloop will likely have minimal environmental benefits if it does not attract ridership from other modes. Construction of hyperloop may cause: - Land clearing, tunnelling or demolition of historic buildings; - Reduced natural land, indirectly harming agriculture and wildlife; - Car dependency and parking demand in case the hyperloop is poorly integrated with other modes of transport; - Noise, barrier effect, visual intrusion and opportunity costs.
Hyperloop spatial development effects at a regional level	- The high speed of hyperloop will improve intercity accessibility. - Hyperloop will make cities less crowded and passengers can travel long distances for different purposes in reduced time.	- Hyperloop will change cities' absolute and relative accessibility at a regional level, bringing distinct parts of a country together. - Redistribution of the economy. - Hyperloop may concentrate services on profitable and major cities, causing marginalisation risk (due to reduced service levels and limited access) for intermediate cities bypassed by the hyperloop. - It may cause the backwash effect, where core cities are drawn closer while distant places tend to get more remote. - An imbalance may occur between cities connected to hyperloop and those disconnected. **Hyperloop-connected cities will likely:** - Improve position in the urban hierarchy; - Facilitate both decentralisation and concentration; - Create new location advantage for individuals with more opportunities and high-level commercial activities, improving their overall performance and accelerating immigration; - Show economic advantage as its transport hubs improve the city's status and competitiveness; - Possibly lead to economic spill-over, spatial competition, increase in land value and cost of living—gentrification may cause people to move to nearby unconnected cities, triggering their growth. **Hyperloop unconnected cities will likely:** - Experience unemployment and reduced accessibility; - Some development opportunity based on the type of city connected to the hyperloop: **Major cities:** - Hyperloop connection will likely enlarge their already dominant nature and thus become more competitive. **Intermediate cities:** - May overcome isolation, improve their location advantage and attract business activities and tourism.

Source: [4,7,9,10].

Table 4. Hyperloop's indirect effects at an urban level and micro-effects on station neighbourhoods.

	Hyperloop's Commercial Claims	Hyperloop's More Realistic and Expected Implications
Indirect effect of hyperloop at the urban level	- Hyperloop-connected cities may reinforce urban development and growth on an urban level. - Hyperloop may reduce urban sprawl.	- It may cause rapid urbanisation that will decrease cultivated land. - The build out of space in the city is likely not be uniform due to the hyperloop creating a probable imbalance. - The improved status, modernity and value around hyperloop's serviced area may lead to gentrification, and thus promoting urban sprawl. - It may facilitate polarisation, segregation, spatial inequality and centralisation. - Extensive development in hyperloop cities may lead to weakly built physical environments, loss of urban and environmental quality and traffic congestion.
Micro effects of stations on the urban development patterns of adjusting neighbourhoods	- Revitalisation and new development of neighbourhoods around the station area	- Regeneration and revitalisation of formerly derelict areas, brownfield sites and railway properties. - Primarily generative, but depending on context and circumstances, station-adjacent neighbourhoods may or may not act as a catalyst for desirable development and growth patterns. - Effects of a hyperloop terminal and its development perimeter on different zones (accessibility level): **Primary zone** - Most significant number and magnitude of effects; - Highest land prices, high-grade offices and residential functions; - Improved status leading to a high level of dense development. **Secondary zone** - Reachable within 15 min via complementary conventional modes of transport (average speed of 20 km/h); - High development density and land value, but less compared to the primary zone. **Tertiary zone** - Less likely to see development; - High population density around the station area, urban fragmentation and risk of developing a separate 'Island' effect.

Source: [2,4–7,10,12–14].

We concluded from this general review of hyperloop that it is essential to perform detailed analyses and tests under different conditions before considering hyperloop's deployment anywhere in the world. The following attempts to provide such an analysis for the committed Mumbai to Pune hyperloop project. It does this by reviewing the best available relevant information that is publicly available.

2. Case Study: Mumbai to Pune Corridor

2.1. Background

In July 2019, India's government agreed to the Mumbai to Pune hyperloop project in a Public–Private Partnership (PPP). Virgin Hyperloop One (VHO) is the main investor and executer of the project. Besides VHO, there are other actors involved in this megaproject. VHO will collaborate with a private company based in Dubai, DP World (operator for the project) [15]. Additionally, the Pune Metropolitan Region Development Authority (PMRDA) will act as the land provider for the proposed route [16]. Some of the significant aspects of this proposed route are briefly highlighted below.

2.1.1. Importance of the Mumbai to Pune Intercity Connection

The proposed corridor for India's hyperloop lies between the two critical and rapidly growing metropolitan areas of Mumbai and Pune. Both these cities, lying at the heart of their respective metropolitan regions, are in the western part of Maharashtra State and are strong in economic and industrial development [17]. These cities' per capita incomes are amongst the highest in India [18]. Mumbai is known as India's commercial capital, whereas Pune is known for its cultural, industrial and educational factors. It is an automobile, IT, industrial and educational hub [15,19]. The suburbs of these two cities contain 72% of Maharashtra's factories, 77% of its industrial employment and control 88% of its working capital and industrial output [19]. Additionally, the city of Pune is also known for its natural beauty. The city centre of Pune lies around 150 km southeast of the centre of Mumbai [20]. Pune attracts people every weekend for leisure purposes. It is known as a place for those escaping Mumbai's megacity problems but who still want to stay connected to Mumbai. Benefits of the city of Pune, such as higher quality of life, less pollution and lower rent, attract numerous people to live in the city but work in Mumbai [21]. The whole region has a tropical climate [22] with temperatures ranging from around 21 °C to 36 °C [17].

The urban corridor from Mumbai to Pune shows the highest values of the human development index in India [23]. Over the years, the number of passengers along this corridor has grown [15]. The selected corridor for the proposed Mumbai to Pune hyperloop lies along the roadway connecting Mumbai and Pune called the Mumbai to Pune Expressway (MPE). The hyperloop proposal aims to reduce the travel time between the two cities from around 3 h by car to a mere 25 min [16,24]. The demographics of Mumbai and Pune, relevant to this research, are highlighted briefly below.

Mumbai: The Mumbai Metropolitan Region (MMR) consists of Mumbai city and its adjacent satellite cities. The MMR has an area of 6330 km^2 [25] with a population of 24.4 million [26]. However, this research only considers the cities and not the MMR. Mumbai city has an urban density of around 30,000 persons per square km (300 per ha), making it one of the country's most densely populated cities [27,28], and amongst the densest cities in the world. As per [29], the population of the city was 12,442,373 million, growing to 13,127,825 in 2021 [26]. It is important to note that the city consists of 24 wards, and the population density differs within each ward. Based on household income, the population can be divided into four distinct groups. These are low-income people, aspirants (their households own just basic items such as an electrical fan, bicycle etc.), the middle class and high-income people, which represent, respectively, annual incomes lower than USD 3000, USD 3000–6000 and USD 6000–30,000, and higher than USD 30,000 (2008 USD). Mumbai city mostly has middle-class (41.9%) and aspirant households (41.1%), while low-income households and the high-income groups represent only 10.8% and 6.2% [30], though, collectively, these latter groups amount to some 2.23 million people.

Pune: The population of Pune city was 3,124,458 in 2011 [31] and 3,891,823 in 2021 [32]. It has the sixth highest per capita income in India [31]. The highest percentage of Pune's population are aspirants (53.8%) and middle class (28.2%), while low income and high income are 13.2% and 4.9%, respectively [30].

2.1.2. Target Area of Study with Some Selected Implications for Hyperloop Operation

The proposed Mumbai–Pune hyperloop construction will be along the MPE because the land is government-owned and not utilised for living purposes. Therefore, it will not interfere or cause disturbance to people. Since the proposed site is the same as the MPE, the site details are also the same. This section analyses the site in terms of terminal locations along with its economic characteristics. VHO decided to implement the project in two phases. The first phase includes the construction of a test track. The initial test track was proposed from Gahunje to Ozarde (20 km), but is now from Gahunje to Urse (10 km) [33], shown in Figure 1 as the yellow dots. The test track must be proved successful through demonstration and certification of the technology. After its (assumed) success, an additional and final 100–110 km would be constructed in the second phase from central Mumbai (BKC Mumbai) to central Pune (Wakad) with an intermediate stop at Navi Mumbai airport. The red dots in Figure 1 represent these three terminals (written in red) [34]. The remaining four brown dots represent intermediate cities that lie on the corridor with no terminals. VHO has begun planning the test track for the hyperloop between Mumbai to Pune and performing tests in California as the test track for the proposed site (10 km) is not long enough to test hyperloop's potential speed [33,35,36]. Hyperloop was proven to be functional during an operational test track ride with real people in Las Vegas [37]. But due to the pandemic, lack of data and lack of clarity, there has been no progress on the Mumbai to Pune project; however, the project has not been scrapped [33]. Also, earlier in 2022, VHO fired half its staff and for now appears to have changed its focus primarily to cargo transport. The company claims this to be due to the COVID-19 pandemic, as well as regulatory and political issues [37].

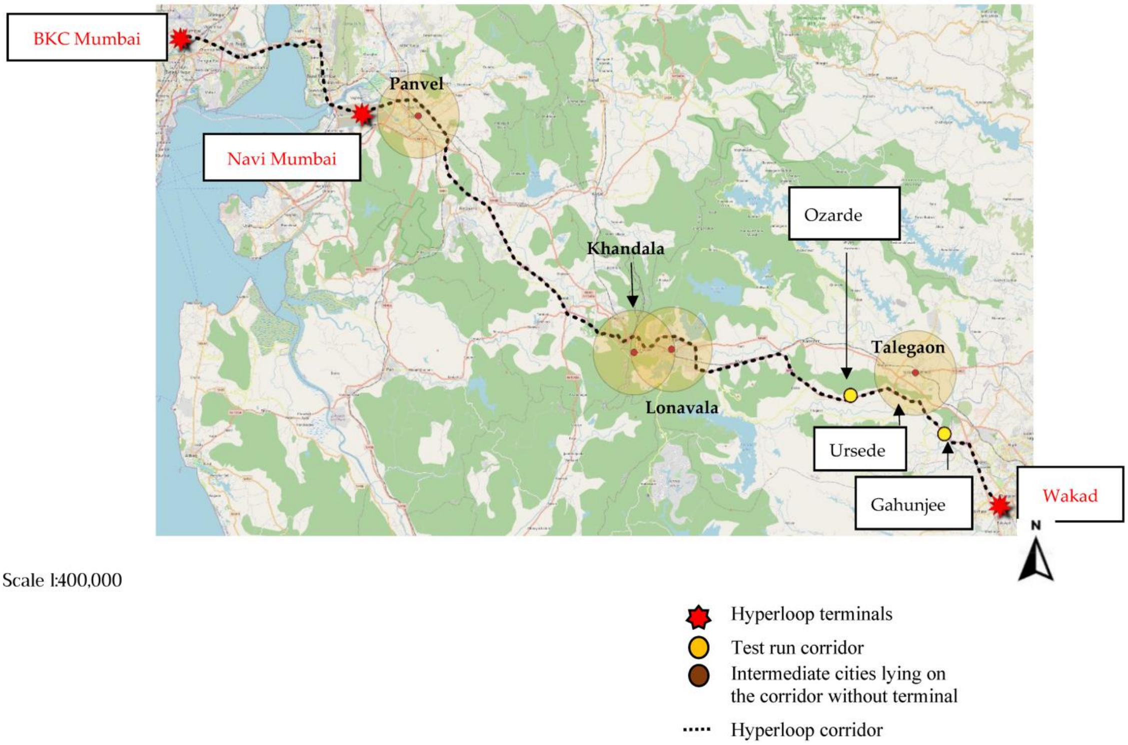

Figure 1. Mumbai to Pune hyperloop corridor showing the location of terminals and intermediate cities. Source: Elaborated and extended by authors based on Qgis.

To date, the MPE is the preferred existing route for intercity travel between the two cities [20]. One of the reasons for this route's preference over other routes for intercity travel is its landscape. Throughout the entire stretch, users experience various natural landscapes, such as fields, patches of uncultivated land and mountains [38]. The corridor's major part consists of flat land apart from 6 kilometres of hilly area called the Western Ghats [19].

The frequency of hyperloop's departures has been tentatively set to every 30 s by VHO to increase passenger capacity in the peak due to the low passenger capacity per departure (see Table 1). With a 30-s headway, passengers will not have to wait at the station and instead will be able to access the hyperloop essentially on demand, depending on the level of demand versus capacity at any time. However, as noted in Table 1, a headway of 80 s may be needed for safety reasons. The proposed hyperloop route consists of many turns due to the mountainous section. Therefore, this would restrict the hyperloop's operational speed to around 500 km/h rather than its maximum potential speed of 1200 km/h [34].

The three-terminal locations of BKC Mumbai, Navi Mumbai and Wakad, are briefly analysed below, along with their assumed catchment area of 5 km, which allows people to reach the proposed terminal location within 15 min by complementary transport modes, assuming an average speed of 20 km/h for these surface, mostly public transport modes, which is a typical global average for such modes [39]. Where this might be lower, the catchment area radius would decline accordingly to maintain a 15-min access time. It is essential to have strong integration of public transport with the proposed terminal, so the hyperloop passengers are less dependent on private cars to reach the terminal location.

BKC Mumbai (Mumbai city): The Bandra Kurla Complex (BKC) is one of the three proposed terminals of the Mumbai to Pune hyperloop. Figure 2 shows the BKC terminal in relation to its 5-km radius area. The red star represents the terminal location.

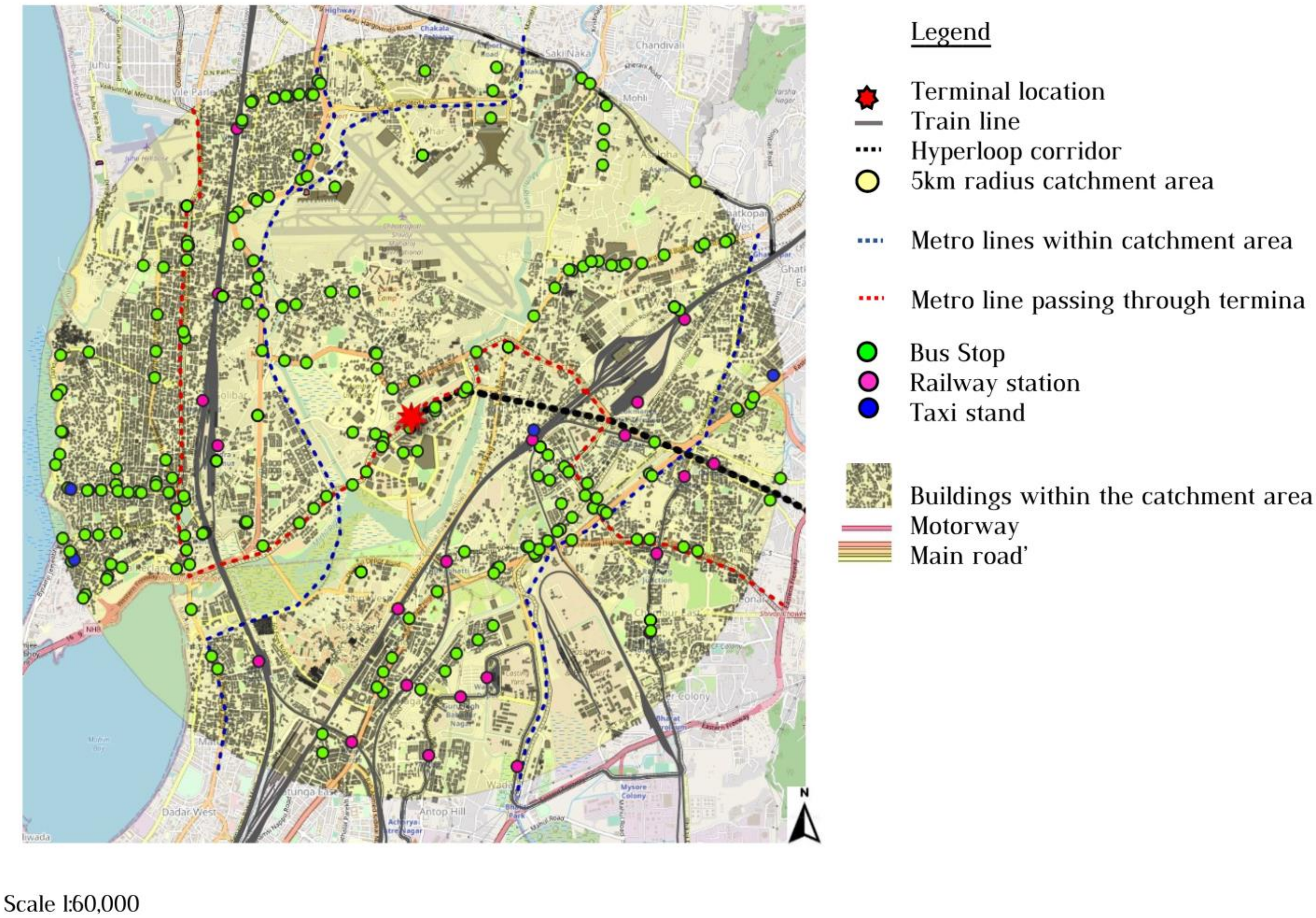

Figure 2. Proposed terminal 1—BKC in Mumbai with its 5 km radius catchment area. Source: Elaborated and extended by authors based on Qgis.

BKC is one of the three Central Business Districts (CBDs) of Mumbai. It is centrally located with numerous business, commercial and residential establishments [40]. In an interview with the director of VHO's operations in India, [41] stated that the proposed hyperloop line from BKC to Navi Mumbai would operate underground. This is to avoid interference with the existing dense urban development in Mumbai city. The red dotted line represents the existing metro line that passes through the BKC terminal located in Figure 2. An underground metro station is currently under construction on the proposed hyperloop terminal location [42]. There is a metro station every 2 min on the metro lines. The proposed hyperloop terminal location will have direct access to metro and bus connectivity. The two major railway termini (Bandra Terminus and Lokmanya Tilak Terminus) are located on the proposed terminal's west and east side [34], 3 km and 2 km, respectively, from the proposed hyperloop station. There is also an international airport 3.6 km from the proposed terminal. According to Census India, the proposed terminal's catchment area lies in two Mumbai districts, Ward H East and Ward H West, with an estimated population density of 40,000 persons and 35,000 persons per square km, respectively [43]. Of the catchment area, 32.5 km^2 is Ward H East while 31.6 km^2 is Ward H West. Therefore, the population of the whole buffer area would be approximately 2.4 million people.

Navi Mumbai: Navi Mumbai is the only intermediate station lying between Mumbai and Pune. It is a planned satellite city of Mumbai, created to decongest it [44]. The red star in Figure 3 shows the proposed Navi Mumbai terminal location. It lies within an international airport which is under construction.

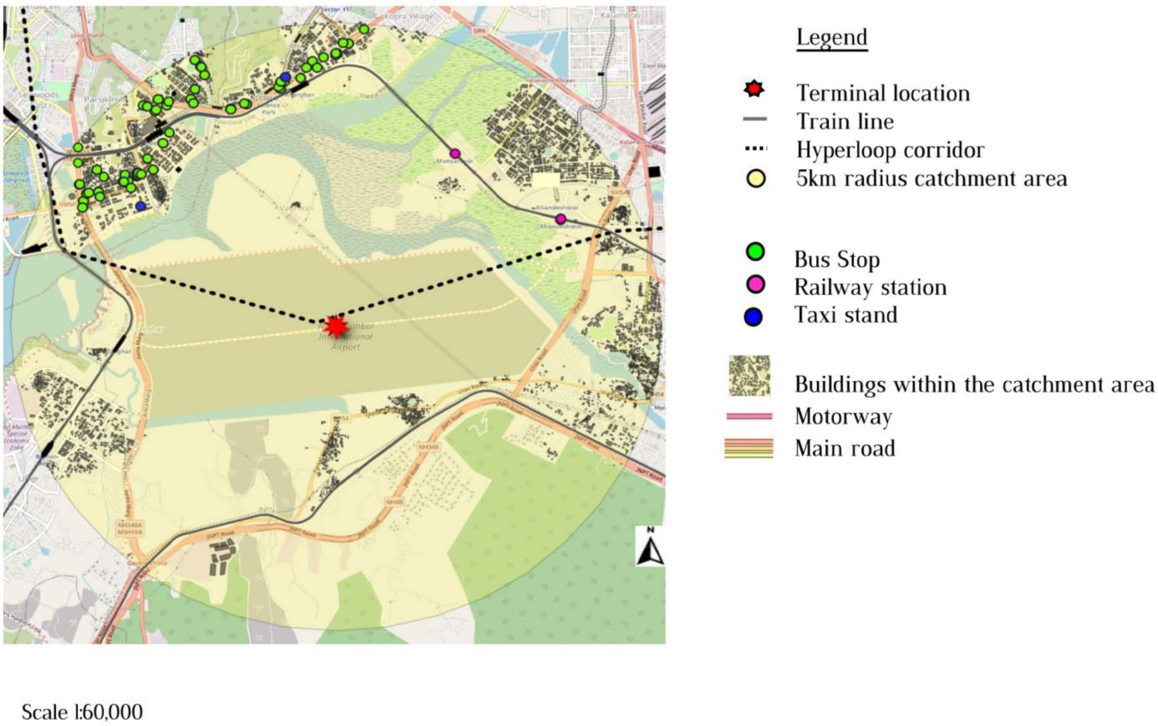

Figure 3. Proposed terminal 2—Navi Mumbai with its 5 km radius catchment area. Source: Elaborated and extended by authors based on Qgis.

The proposed Navi Mumbai terminal lies 32 km from the BKC terminal [45]. The proposed terminal buffer area contains two railway stations and many bus stops located around 4 km from the terminal. Therefore, the integration of the proposed terminal location is comparatively low. The population density of Navi Mumbai is 10,311 persons per square km [29] or very significantly less than in Mumbai proper.

Wakad: The last proposed terminal of the Mumbai to Pune hyperloop lies at the end of the MPE in Wakad. The red star shows the terminal location in Figure 4 and its catchment area (5 km radius).

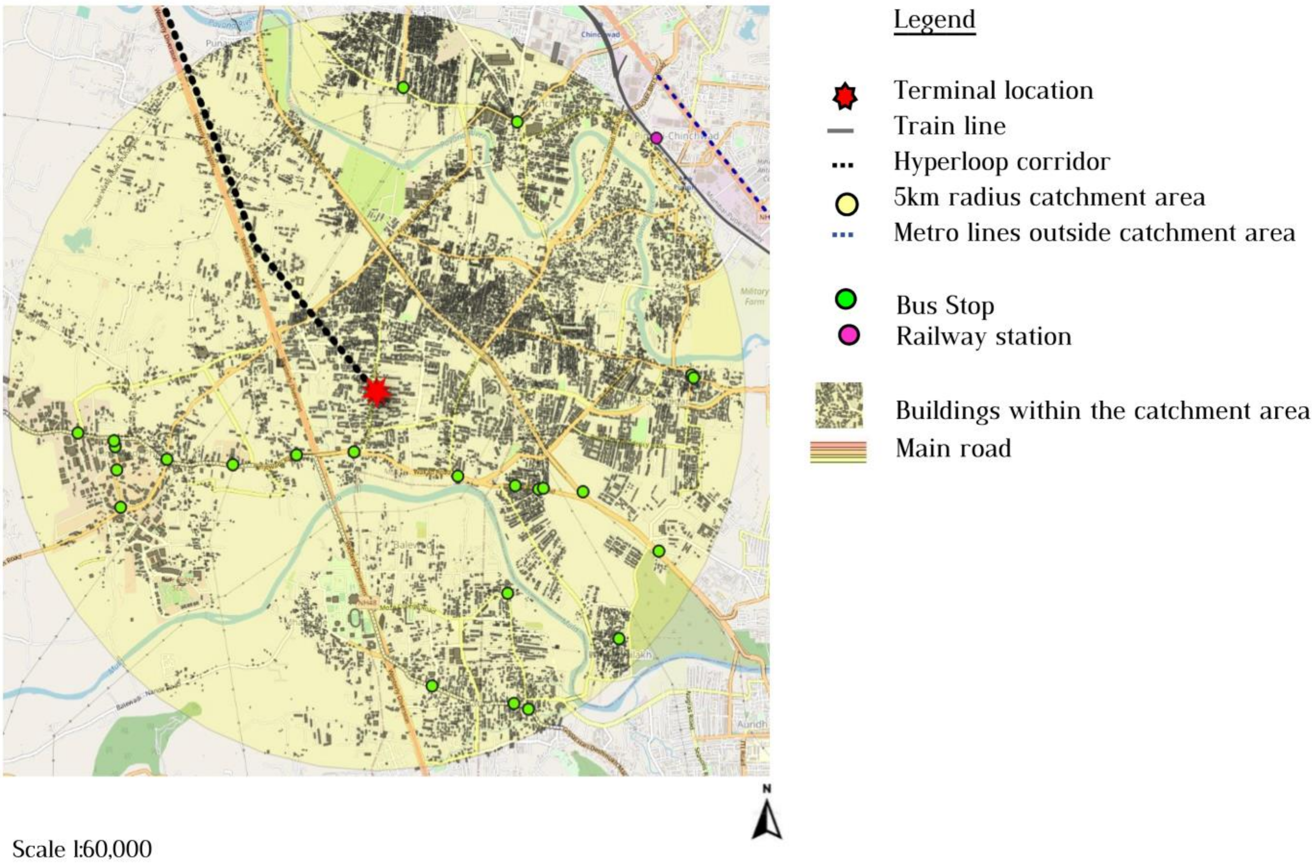

Figure 4. Proposed terminal 3—Wakad with its 5 km radius catchment area. Source: Elaborated and extended by authors based on Qgis.

Wakad is situated on the periphery of Pune. Famously called Pune's educational hub, the area is mostly occupied by universities and companies [46]. According to [34], Wakad has good metro (rail) connectivity. However, there is no metro access to the proposed Wakad terminal within its 5-km radius. Wakad is more intensely integrated for road travel but with few bus stops [46]. The nearest bus stop lies 700 m from the proposed terminal location (roughly a 10-min walk depending on conditions). For passengers with luggage, this would mostly be unacceptable. Therefore, there is a requirement to improve integration via public transport. The nearest railway line is around 6.8 km away. This takes around 20 min to reach by road. The urban density of Pune is 20,000 persons per km based on a 2011 population of 3,124,458 and urban land area of 156 km^2 [47]. Therefore, the approximate population of the buffer area of the terminal is around 1,570,000 persons.

2.1.3. Cost of the Proposed Hyperloop

Current criticism of this hyperloop line comes majorly from doubts regarding the project's economics. According to VHO, the project's expected cost is USD 70 million (USD) per km [24]. Walker's [2] paper suggests a 32.2% increase in hyperloop construction cost over those estimated by companies, so that the minimum cost would possibly increase to USD 92.6 million per km. Further, the addition of [48] minimum of 50% of overrunning costs in megaprojects would take the proposed hyperloop's cost to a possible minimum of USD 139 million per km, which is twice the amount predicted by VHO. At these prices, hyperloop costs also need to be weighed up against the cost of building more conventional, high-quality public transport systems in Indian cities, which is essential to understand if the intercity connection via hyperloop will represent an overall beneficial project. It is, therefore, necessary to first look at the importance of the Mumbai to Pune intercity connection via hyperloop.

2.2. Importance of the Mumbai to Pune Intercity Connection via Hyperloop

2.2.1. Intercity Connections

Currently, passengers commute between the cities by road, rail and air travel. The most influential factors for these travel modes are fare, time and the transport infrastructure [49]. Road travel takes 2–3 h and travel by train takes 3–4 h, while air travel takes 55 min [20]. It is important to note that road travel here focuses on cars and buses as trucks (mainly freight) and two-wheelers (less common for long distance trips) are out of this research's scope.

Two intercity routes connect Mumbai to Pune through road travel. These are the "Mumbai to Pune Highway (NH48)" and the already-mentioned "MPE" [17]. MPE was constructed long after the NH48 to relieve it from the growing number of vehicles and congestion, which caused delays and accidents [17,19]. However, the increasing growth of cars on the MPE has led to similar issues as on the NH-48 [50], such as increased congestion, travel time, road accidents, air pollution and consequent health issues. All these factors have caused a loss of economic productivity [51].

Road travel by car and bus is time-consuming, unreliable and not eco-friendly [20]. Recent years have seen a decline in rail passenger travel after the MPE construction [52]. The most significant limitation of the intercity connection through rail is its high travel time, and the low quality of trains [53]. On the other hand, the journey time by flight is the shortest compared to other modes of transport [20], though terminal times and transfers to final destinations reduces this advantage as indicated below.

As fares are the most influential factor attracting most passengers' modal choice in India, air travel is the least preferred way of intercity travel. Also, for medium distance travel, this travel mode is less preferred than road and rail travel because the total travel time would be two to three times more than the actual flight time [53]. The corridor requires a reduction in transportation costs, travel time, increased safety, improved passenger comfort and reduced carbon emissions [17]. There is, thus, a need to invest more funds in higher quality transportation projects. This is partly why hyperloop is being experimented with.

2.2.2. Modal Share between Mumbai and Pune

Seventy-five million passengers travel between the two cities annually [15]. Out of these, 71% of passengers prefer to travel by car, 20% prefer the bus, 7% prefer train and only 2% prefer flights. Table 5 shows passengers' detailed travel behaviour between Mumbai and Pune and their average cost per passenger-km. Costs may differ depending on fluctuations in fuel prices, featured facilities and travel companies [20].

As per Table 5, 110,000 vehicles travel intercity between Mumbai and Pune daily [20]. Clearly, road travel is the preferred choice for the corridor. This is due to the combination of incentives such as time, cost and comfort. However, the value of the incentives provided by road travel is dropping every year due to increasing congestion. When a similar situation arose on the NH-48, MPE's construction took place. Based on this trend, the future of intercity passenger demands along this corridor are likely to be mostly met by road-based transport. This will add to the challenge facing India's national energy security and increase its greenhouse gas output. Therefore, instead of investing funds in another roadway project, there is a need to invest funds in more efficient and high-quality transportation projects, allowing for a healthy, economically feasible intercity connection.

Table 5. Passengers' travel behaviour and cost per km of different modes between Mumbai and Pune.

	Road Travel 110,000 Vehicles Per Day Source: [20]	**Rail Travel 24 Trains Per Day Source: [54]**	**Air Travel 29 Connecting Flights Per Day Source: [55]**
Number of passengers per day	80,000 cars 145,890 passengers: average occupancy 1.82 1000 buses Source: [50]. 41,096 passengers: average occupancy 41.	14,384 passengers	4110 passengers
Cost per passenger km (This cost represents the price for one passenger to travel 1 kilometre by the respective mode in (2019 USD)	Passenger car USD 0.20 Bus (air conditioned.) USD 0.06 Bus (non-air conditioned.) USD 0.03	General class USD 0.02 2nd Class USD 0.03 1st Class USD 0.04	USD 0.60

Source: Elaborated and extended by authors based on [20,53].

Companies have claimed hyperloop to be a good substitute for intercity travel on routes that require high capacity, reduced time and improved rail services against other modes. They also claim it to be economical and affordable to all [15]. According to them, the hyperloop will minimise the travel time between the two cities and would ease severe congestion on the expressway and, hence, reduce road accidents [34]. However, the decrease in traffic congestion on the MPE might not be the case, at least in the long run. Kenworthy [56] refers to "induced demand" whereby any improvements in capacity and travel time on roads is generally consumed by increased attraction of the route and more demand. Concretely, once a road system is established, the travel demand cannot be stopped (unless through economic or other restrictions and disincentives) and typically leads to congestion and further road expansion. Perhaps the MPE might be relieved of cars due to the hyperloop initially, but eventually, new vehicles will likely return and fill the freed space.

The government of India agreed to the construction of the hyperloop based on the commercial claims of its benefits. Through the hyperloop, India's government has planned to boost rail's share of intercity travel between Mumbai and Pune by upgrading infrastructure and technology. It is, however, already clear from preceding information, that the price of hyperloop construction would likely be much higher than predicted by these companies. It is also imperative to check the viability of other claims and analyse how many passengers the Mumbai to Pune hyperloop might shift from the above-mentioned existing modes. We have reality-tested this with simple available data, which are highly suggestive, though further work on a detailed travel model should be performed.

2.2.3. Possible Commuters on the Mumbai to Pune Hyperloop

To calculate the minimum potential commuters that may be attracted by hyperloop from the existing modes of transport, it is essential to highlight a few previously mentioned data that will aid in the calculations.

The hyperloop is expected to run for 19 h (5 a.m. to 12 a.m.) and use the remaining 5 h for maintenance. As reported by RoadBounce (a technology which identifies road conditions and traffic safety indicators), the current Mumbai to Pune corridor seems to face minimum traffic from 12 p.m. to 4 p.m. [57]. Since the Mumbai to Pune hyperloop is not operational, its peak hours are assumed to be like metro peak hours in India—that is

8 am to 12 noon and 4 pm to 8 pm, providing 11 h of off-peak operation and 8 h of peak hour per day. The hyperloop will have a minimum headway of 30 s (120 departures per hour) during its peak hours and 2 min (30 departures per hour) during its off-peak hours. Given hyperloop's carrying capacity, this will allow a maximum of just 3360 passengers every peak hour, and only 840 passengers each off-peak hour. Based on these data, this would allow 36,120 passengers per day, assuming a full capacity with every departure. The cost of the hyperloop is assumed to be comparable to air travel due to previously mentioned reasons. The hyperloop will also not operate at speeds higher than 500 km/h due to topographical constraints and will consequently take 25 min to cover the distance of 120 km. The current air travel between Mumbai and Pune of 118 km takes 55 min. Therefore, even at a speed much less than the potential claimed maximum speed of hyperloop (1200 km/h), there is still a speed advantage over flying, especially considering airport terminal times and transfers.

Since this technology is new, there is no operational example of hyperloop or indeed other operational HS ground transportation in India to show the expected shift from existing modes. Also, the feasibility study of the hyperloop between Mumbai to Pune, which suggests many socio-economic benefits, has still not been made public. Therefore, and in keeping with our previous paper, the feasibility study of conventional HSR in India is assumed to give the expected results of the hyperloop's performance.

Ramulu and Selvakumar [53] developed a binary logit model to find passengers' probable shift to the proposed Mumbai to Ahmedabad HSR. According to their findings, the passenger shift to HSR may be more than 80% when the fare is 1.5 times higher than existing travel options and 1 to 8% when the fare is three times the fare of an existing mode of transport. The hyperloop between Mumbai to Pune is expected to act similarly. Therefore, to work out the scenario, it is essential first to analyse the fare of existing modes of transport compared to the likely fare of hyperloop. Figure 5 represents the number of times higher the hyperloop fare is expected to be, compared to the existing modes of transport.

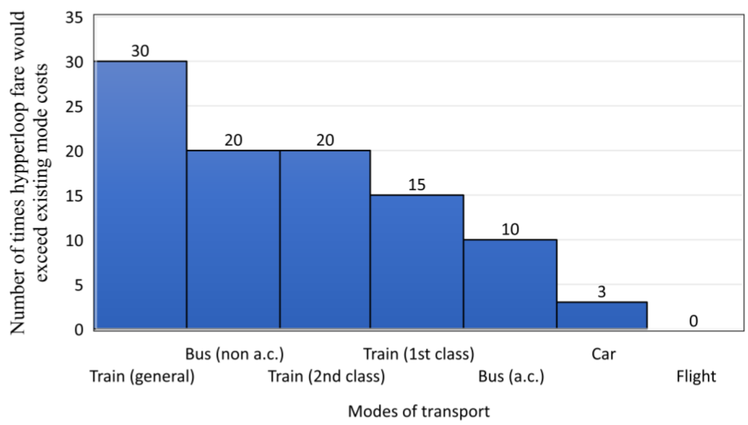

Figure 5. Number of times higher the proposed hyperloop fare could be compared to other existing modes of transport. Source: Elaborated and extended by authors based on data from previous section.

As shown in Figure 5, the flight fare is the same as the hyperloop fare, making the maximum expected passenger shift from air travel to the hyperloop to be 100%, especially given less waiting time for boarding a service and a better located destination at both ends. However, a hyperloop will not have windows, which may be claustrophobic for passengers. In practice, a lot of existing passengers from air travel may still prefer planes because they may not be prepared to travel in a windowless tube. It might be assumed then that the passenger shift from air travel could be in the range of 50 to 100%. The fare of the hyperloop is three times that of a car. Therefore, based on the evidence previously presented, there is a possibility of a shift of passengers from car to hyperloop of between 1 to 8%. It can be assumed a fare higher than three times the car cost will have a negligible shift of passengers.

The hyperloop fare is 30 times higher than the general class rail fare and ten times higher than an air-conditioned bus. Therefore, the proposed hyperloop may not be able to shift passengers from any other modes apart from planes and cars.

Figures 6 and 7 represent a hyperloop system with its capacity to carry 36,120 passengers (per day) and the percentage of passengers shifted from cars and planes in two case scenarios. Figure 6 shows hyperloop composition when there is a passenger shift from cars of 1% and planes of 50%, while Figure 7 represents the hyperloop with a passenger shift from cars of 8% and planes by 100%.

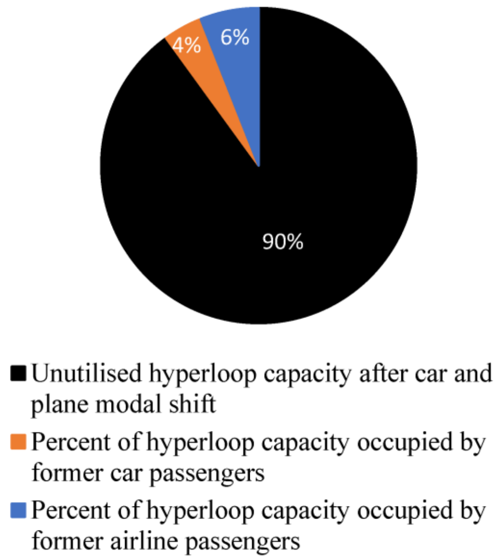

Figure 6. Scenario 1: Hyperloop system (capacity of 36,120 passengers per day) when there is a passenger shift from cars by 1 percent and flight by 50 percent. Source: Elaborated by author based on data from previous section.

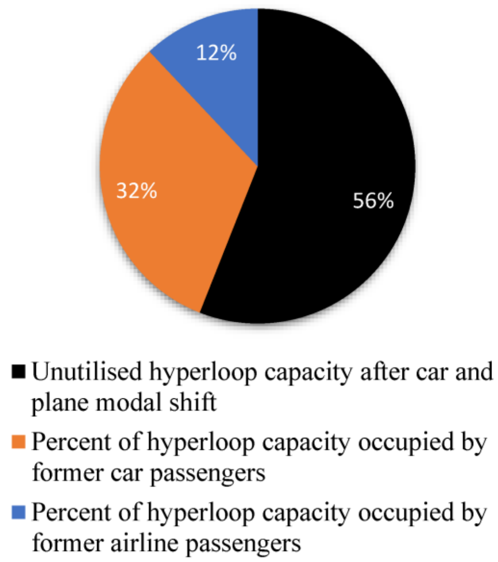

Figure 7. Scenario 2: Hyperloop system (capacity of 36,120 passengers per day) with a passenger shift from cars by 8 percent and flight by 100 percent. Source: Elaborated by author based on data from previous section.

It is clear from Figures 6 and 7 that even with the low carrying capacity of hyperloop, after the shift of passengers from airlines and cars, around 56–90% of the hyperloop capacity may remain unused. This is because the hyperloop may not be able to shift passengers from other modes of transport at the rates required to help fill its capacity due to its high fare.

Therefore, it seems clear that even with its low carrying capacity, hyperloop may impact only a tiny cohort of the existing passengers commuting between Mumbai and Pune, notwithstanding that as the level of prosperity grows in the two cities, more people may gradually be able to pay the required fare. However, in the short term, without making it more affordable, the success of such a system with high construction costs may be unachievable. Having said this, transfer of existing passengers between Mumbai and Pune from other modes is not the only potential source of passengers. The hyperloop could well generate extra trips, normally called "induced traffic" [56]. It is also, therefore, essential to analyse the potential new hyperloop users of the two cities' population connected by the hyperloop. By implication, it is then vital to analyse the proposed corridor's city populations based on their income group mentioned in the general background section. Before examining this, it is crucial to understand how different income groups' disposable income impacts their travel.

Thomas et al.'s. [58] findings use disposable income variables to calculate potential users of modes of transport based on fares in India. Travellers rely more on their household income than personal income to make trips and higher household income increases disposable income. Travellers with higher disposable income choose more costly, comfortable and less time-consuming modes of transport. Therefore, as the household income increases, travellers' trips by plane increase and other travel modes such as bus and rail decrease.

High household income passengers could, therefore, afford to take the hyperloop more frequently than middle-income groups. Middle household income groups may afford hyperloop, but they would likely be occasional travellers rather than frequent. Trains and buses are the most important modes of transport for low-income households or aspirants [49]. Therefore, it is not easy to influence low-income households as potential passengers for the hyperloop. Figures 8 and 9 respectively represent the population (%) of the city of Mumbai and Pune as potential users of the hyperloop based on their income groups. The population is divided into three groups based on their income: frequent users, occasional users and users that cannot afford hyperloop.

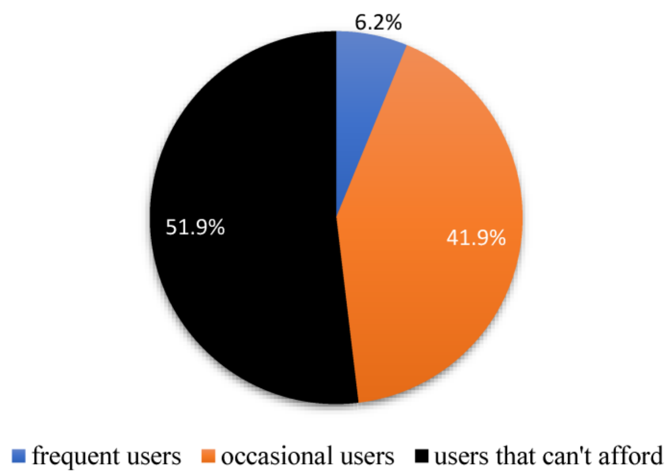

Figure 8. Percentage of population of Mumbai in terms of users of Mumbai to Pune hyperloop. Source: Elaborated by authors based on data from previous sections.

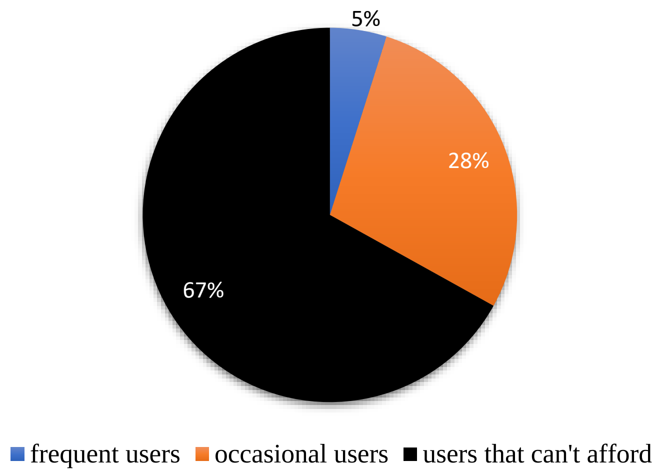

Figure 9. Percentage of population of Pune in terms of users of Mumbai to Pune hyperloop. Source: Elaborated by authors based on data from previous sections.

Figures 8 and 9 show that a very tiny section of Mumbai and Pune's population may afford the hyperloop and therefore be potential hyperloop users. This is because a major part of the population is comprised of low-income households and aspirants who could not afford the hyperloop. For a better understanding of how many of the high-income and middle-income populations might make a daily trip on hyperloop, two case scenarios are assumed in the city of Mumbai (population of 12,442,373) for demonstrative purposes. Scenario 1 is the assumption that 10% of the high-income population and 5% of the middle-income population might make a daily trip on hyperloop. Scenario 2 is the assumption that 20% of the high-income population and 10% of the middle-income people might make a daily trip on hyperloop. These are the induced new trips and are assumed for indicative purposes to test in a broad sense hyperloop's possible viability and provide a very good initial reality test. A more detailed modelling study may produce different results. Based on the two case scenarios, 10,770 and 22,840 additional vehicle trips, respectively, by the hyperloop pods would be needed to cope with this demand alone.

For more clarity, and a slightly different perspective on the above problem, it is useful to understand the percentage of high and middle-income people who would need to make a daily trip on hyperloop to fill all the likely remaining capacity after modal transfers. For the sake of simplicity and to assist in this theoretical calculation, it is assumed that there would be no transfer of existing trips from other modes and that the hyperloop would derive all its patronage from just the high-income people. As shown, Mumbai has a population of 12,442,373 and 6.2% is the high-income population. Therefore, there are 771,426 high-income people in Mumbai. Based on the daily carrying capacity of hyperloop (36,120 passengers), the hyperloop could only provide enough daily capacity for 4.7% of them to use the hyperloop, should they want to. Similarly, Pune has a population of 3,124,458, from which 4.9% is the high-income population. Therefore, using the same logic, the hyperloop could only provide enough daily capacity for 23.5% of them, should they want to travel. After factoring in the transfers of trips from other modes, it would mean that an even lower percent of high-income people could find a seat each day on the available departures. In Mumbai, only 4.2% to 2.6% of the high-income groups are likely to find a seat on the hyperloop, whereas in Pune, 21.3% to 13.3% are likely to find a seat. Therefore, hyperloop would only have a small potential to handle new induced trips.

Given these numbers, the question, however, is: would there, in reality, even be 4.7% or 23.5% of the high-income people in Mumbai or Pune, respectively, who would want to make the intercity trip on hyperloop each day? Passengers who are claustrophobic, for example, may opt-out. This can only be clarified by more detailed surveys and modelling.

Despite the challenges outlined above, the hyperloop demonstration track was to be constructed within three years of the agreement. The project would then take a further five to seven years to complete [15]. However, as mentioned earlier, the project has seen no progress, but once commenced, the project will take a minimum of eleven years to complete [59]. Although the hyperloop is an advanced and innovative technology, current economic, safety and comfort issues exist and with the assumed high fare, its low carrying capacity may not, in the end, make a difference, since most of the hyperloop capacity might remain unutilised. This is mostly because only a small percentage of higher-income groups would likely become frequent users. This suggests that for the Mumbai–Pune corridor under current socio-economic realities, the hyperloop could be considered more of an elitist dream, than an effective addition to the region's mobility infrastructure.

To be fair, however, it is imperative to assess whether there are policies that might make the hyperloop more economical and affordable to all, while at the same time maintaining the need to also assess whether hyperloop is a good use of public money in the light of other desperate improvements needed to mobility systems in Indian cities. The above simple investigation, using easily accessible data, highlights the need for much more clear-headed and detailed work to assess whether such a large investment is worthwhile.

2.3. Mumbai to Pune Hyperloop's Impact on Other Urgent Mobility Needs in India

2.3.1. Mumbai to Pune Hyperloop in Comparison to India's Other Urban Mobility Needs

The Indian government, overall, does not meet the population's demand for essential public transport [60]. The physical coverage of formal public transport networks in Indian cities is less than most cities worldwide [51]. In India, privately operated public transport (informal public transport) such as rickshaws, auto-rickshaws and minibuses cater to the people's mobility needs more than formal public transport offers, which are often uncomfortable, unreliable, low capacity, unsafe and cause immense pollution and congestion [60]. In India, BRT systems exist in only twelve cities [61], while just fourteen cities have operational metro systems (Kolkata, Delhi, Chennai, Bengaluru, Hyderabad, Jaipur, Gurgaon, Mumbai, Kochi, Noida, Nagpur, Kanpur, Ahmedabad and Lucknow) [62].

This has caused many people to prefer personal vehicles for making their journey. Given the financial and institutional limitations, it will not be easy to provide adequate formal public transport services [60]. Hence, it is risky to invest funds in constructing a hyperloop, which is very expensive per kilometre to build and is still in its testing phase. Consequently, traditional transport modes need to be examined with flexible options adjusted with the varying demand to avoid expensive redundancies. Therefore, we need to analyse the cost of constructing traditional high-capacity metro and BRT systems to check the wisdom of hyperloop investment.

Comparison of the cost of metro systems with the proposed cost of hyperloop in India: A metro is a type of mass rapid transit system that operates on dedicated rights-of-way at speeds typically up to 80 km/h [63] and has a capacity of 50,000–75,000 passengers per hour in one direction. Metros in India typically have headways of 2 min, due to high city densities and intense demand. They have security scanning and screening at the entrance and are affordable, except for the lowest income groups which earn USD 2 per day or less [64,65]. A 10-km distance covered in the Delhi metro costs passengers USD 0.13; Chennai, Bengaluru and Lucknow metros cost USD 0.40, and USD 0.80 in Mumbai. Most urban poor are unable to spend USD 0.13 on a shared auto, so spending on metro fares is out of question [66].

Though metros have reduced road congestion, the impact is less than is possible due to limited coverage within cities and lack of control over congestion through proper charging for road space [64]. Another major reason for this is the absence of last-mile connectivity [66]. Table 6 provides typical costs of constructing metro projects in different Indian cities and compares it to that of hyperloop.

Table 6. Comparison of the cost of metro projects in India with the proposed hyperloop.

Metro System	Cost of Construction (USD Million per km in 2011)	Number of Times Less than the Minimum Cost of Constructing Hyperloop (USD 139 Million/km)	Kilometres of Metro Construction Possible with the Total Cost of Proposed Hyperloop of 120 km (Approximately USD 16.680 Billion)	Population of Metropolitan Area [29,67,68]
Delhi metro	Average: USD 26 Underground: USD 74	5.3 times	642 km	16,349,831
Jaipur metro	USD 50	2.8 times	334 km	3,046,163
Mumbai metro	USD 19	7.3 times	878 km	18,394,912

Source: Elaborated and extended by authors based on [64].

Even though the average cost of a metro per km differs, depending on the city and its geology, topography and other conditions, construction costs are lower than that of a hyperloop by three to eight times.

With hyperloop's total estimated cost, a metro system in Mumbai of around an additional 880 km could be constructed. The current populations of these metro areas show the high number of people that could potentially be served with such long networks of metro. Clearly, investing funds in metros could provide much greater network lengths of high-quality public transport in key high density Indian cities with significant mobility issues, than the equivalent amount of spending on hyperloop.

Mumbai to Pune Hyperloop in comparison to Bus Rapid Transit Systems: Delhi and Pune began with the first pilot BRT systems in India in 2006 and 2008, respectively [51,69]. BRTs create a robust integrated system by connecting stations, vehicles, services and rights-of-way with technology [70]. BRT provides comparatively good operating speed relative to congested roads and provides an adequate level of service. For the success of a BRT corridor, it is essential to establish a closed, completely segregated, reserved (i.e., exclusive) right-of-way, but India still lacks in this factor [71]. Only three BRTs out of the nine operating in 2013 were closed systems, the rest were open (i.e., mixed services with the local street and no exclusive BRT corridor) [72]. These cities also adopted off-board ticketing, which aided service punctuality [73].

The mean road traffic speed across cities in India in 2018 was 24.4 km/h [74]. BRT in Indian cities travels at an average speed of 25 km/h [75] with headways up to 30 s [71]. Even though the BRT speed is around the same as the average traffic speed in Indian cities, it is still low, mainly due to lack of completely reserved or closed rights-of-way. Speed cannot be increased by reducing the number of stops due to the high-density corridors. The BRTs in Indian cities have a potential capacity of 25,000 passengers per hour in one direction [75] and a strong potential to attract passengers from cars [71]. Based on the general success of BRT and a comparatively low number of existing operational BRT systems in India compared to what could be, there is a requirement for more BRT systems in Indian cities [75]. Table 7 provides the cost of constructing BRT projects in Indian cities and compares it to that of hyperloop.

Table 7. Comparison of cost of BRT projects in India with the proposed hyperloop.

BRT	Cost of Construction (USD Million per km in 2010)	Number of Times Less than the Minimum Cost of Constructing Hyperloop (USD 139 Million/km)	Kilometers of BRT Construction Possible with the Total Cost of Proposed Hyperloop of 120 km (Approximately USD 16.680 Billion)	Population of Metropolitan Area [67,68,76]
Delhi	USD 2.0	69.5 times	8340 km	16,349,831
Ahmedabad	USD 1.5	92.6 times	11,120 km	6,361,084
Jaipur	USD 1.4	99.2 times	11,914 km	3,046,163

Source: Elaborated and extended by authors based on [75].

Table 7 shows that the cost of constructing BRT in Indian cities is radically lower than that of hyperloop. For the cost of the whole Mumbai–Pune hyperloop project, thousands of kilometres of BRT infrastructure could be constructed in several Indian cities, benefiting many more people. The existing public transport systems require efficient and utility-based public transport systems with safe and secure support systems. The relatively low cost of public transport construction has a higher potential to benefit much more of the population and transform Indian urban transport systems [75]. Given Mumbai and Pune's socio-economic profile, hyperloop's construction cost is not a viable option. The comparisons in Tables 6 and 7 prove that the cost of construction of BRT and metros in Indian cities is fundamentally less than that of hyperloop. Therefore, the importance of constructing public transport such as metro and BRT seems clear and is more significant in its benefits [77]. Such systems improve urban mobility and accessibility for basic needs and provide a solution for existing public transport challenges and future demands [75].

2.3.2. Impact of Hyperloop's Projected Costs on the Funding of Other Mobility Needs in India

It is clear from the above that investing funds in public transport projects such as metro and BRT is more reasonable and, very likely, much more socially equitable than hyperloop investment. However, it is imperative to know the impact of hyperloop's projected costs on funding metro and BRT mobility needs. In India, public transport funding has come under transport infrastructure projects [41]. It is first necessary to look and understand how the government allocates funds to India's urban infrastructure projects.

In India, different urban infrastructure projects are assigned under different departments or ministries. The total funding for transportation infrastructure by the federal government of India in 2020–2021 was around USD 25 billion. Out of this, USD 12.4 billion is allocated to the Ministry of Road Transport and Highways, USD 9.4 billion to the Ministry of Railways, USD 513 million to the Ministry of Aviation, USD 243 million to the Ministry of Shipping and USD 2.6 billion to the Ministry of Housing and Urban Affairs [78–82].

Figure 10 shows the percentage distribution of ministries' allocation of funds for different modes of transport in India. Only 10% of the funds go to mass transit such as metros and BRTs. This helps to explain why BRTs and metros exist in only twelve and fourteen cities of India, respectively. Around 38% of the funding is allocated to railway infrastructure in India.

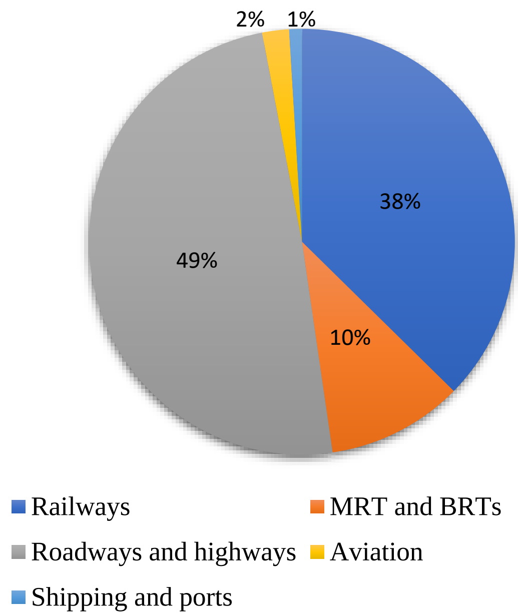

Figure 10. Percent allocation of infrastructure funds for transport in India, 2020–2021. Source: Elaborated and extended by authors based on [78–82].

Despite this, Indian railways are low quality, poorly constructed and maintained and inefficient [83], which is why the government of India recently started focusing and investing more on railways [84]. According to researchers, there is an urgent need to improve existing rail quality [85]. Logically, however, the government needs to first evaluate and address the existing problems before investing in new projects. Furthermore, investment in roadways takes up 49% of transport infrastructure spending in India [51].

This suggests that the government prioritises roads over mass transit and helps to explain the poor performance of public transport. More roadway connections inevitably lead to increased use of personal motorised vehicles [56,86]. Therefore, there is an urgent requirement to invest most funds in mass transit rather than roadways.

As mentioned earlier, the Mumbai to Pune hyperloop is to be funded through a Public-Private Partnership (PPP) with VHO, which is the main investor in the project. Since there has been no further progress in the Mumbai to Pune hyperloop since 2018, it can be stated that the proposal is still in an early stage with no publicly available information on its funding. Also, as mentioned earlier, VHO has changed its focus to a cargo-first strategy, putting the development of the hyperloop in India on hold [37]. Due to this decision, in November 2022, the Virgin Group removed its name from VHO, thus reverting to just Hyperloop One [87]. However, the question remains whether it is worthwhile to have costly ultra-high speed cargo services. Notwithstanding this, in case the Mumbai to Pune project is pursued, in the absence of information to the contrary, it could be assumed that the part of the investment to be funded by the government of India might come from the funds available for mass transit such as BRTs and Metros (USD 2.6 billion) or heavy railways (USD 9.4 billion) or both (USD 12 billion), and probably not from the roads allocation.

Clearly, India does not have the capacity of funding the complete proposed hyperloop project on its own. But the question is even in a PPP (where the construction of the proposed hyperloop may be funded partly by the government and mostly by its investor VHO and private companies), will India be able to fund its share of the hyperloop given the allocation of transport funds for infrastructure (MRTs and BRTs) or heavy rail projects? Let us assume, just for argument's sake, that the Indian government pays 10% of the proposed hyperloop cost (around USD 1.6 billion) while the rest is funded by its investor and private companies. This means it may absorb more than 50% of the funds allocated to mass transit. In case the government decides to use its heavy rail funds instead, it will absorb around 17% of the funds allocated to heavy rail. Therefore, even if contributing just 10 percent of the total cost of the proposed hyperloop, there is a major loss of the limited funds allocated for existing desperate mobility needs throughout the country.

Based on the above, either the success or failure of the project post-construction has a negative impact. If the project is successfully completed, only the high-income groups will be able to afford it, amounting to only a tiny section of the population. Additionally, hyperloop's construction would probably absorb funds otherwise allocated to critical metro, BRT or heavy rail projects. If the hyperloop project is declared unsuccessful, it is a loss of funds, which could have been used for metro, or BRT. Therefore, it is imperative to critically evaluate the funding of the hyperloop or make it more significantly economical.

3. Evaluation of the Mumbai to Pune Hyperloop Case Study in Relation to Available Literature

This section analyses hyperloop's application to the Mumbai to Pune corridor by examining the findings from the literature review in [4] in relation to the case study. Tables 8–12 represent the most crucial expected physical planning, economic, human, technical, environmental, urban planning and transport implications of the proposed Mumbai to Pune hyperloop by showing its most significant positive and negative effects, represented in green and red squares, respectively. For every positive effect a green square score is given whereas for every negative effect a red square score is given. Collectively, these give an indication of the overall level of risk in embarking on this project.

Table 8. (**a**). Summary of the most important negatives and positives of the Mumbai to Pune hyperloop in terms of its physical factors. (**b**). Summary of the most important negatives and positives of the Mumbai to Pune hyperloop in terms of its physical factors.

	(a)	
Physical Factors	**Positive Effects**	**Negative Effects**
Assessment of Mumbai to Pune corridor as a potential corridor for a hyperloop line. (Based on criteria for the selection of the hyperloop corridor).	**1. Links major city of Mumbai with intermediate city of Pune.** The route offers: - Two important growing cities; - High economic productivity; - It is one of the most essential and dense intercity connections in the country; - A high number of existing commuters (205,480 passengers daily).	**1. The route consists of a hilly section and several curves.** - Will not be able to use full potential speed of 1200 km/h.
Travel time of Mumbai to Pune hyperloop	**1. Travel time would be faster than buses and trains.**	**1. Proposed hyperloop will travel at a speed of not more than 500 km/h.** - 700 km/h less than the potential speed of hyperloop; - Almost same as planes. **2. Security screening, transit and baggage handling may increase the total travel time.** - Similar security requirements to an airport.
Energy (Electrical grid)	**1. Mumbai to Pune corridor has a tropical climate. It receives an abundance of sun and rainfall throughout the year. It will be cheaper and energy-efficient to use solar and hydro energy to power the electrical grid.**	
Score		
(b)		
Physical Factors	**Positive Effects**	**Negative Effects**

Table 8. *Cont.*

Corridor and terminals of Mumbai to Pune hyperloop	**1. BKC Mumbai to Navi Mumbai to be constructed underground.** - Does not disturb the existing urban setting.	**1. BKC Mumbai to Navi Mumbai to be constructed underground.** - Increase in the construction cost. **2. Navi Mumbai to Wakad to be elevated on pillars 30 m apart.** - Visual pollution; - Limited space of land between the pillars might be left unutilised. **3. Several curves** - Increases length of corridor which increases the overall land space and construction costs. **4. Land use effect: May induce sprawl** - Consumption of arable and agricultural land.
Capacity and efficiency of Mumbai to Pune hyperloop (It will run 19 h in a day).	**1. Short headway** - Off-peak hours (Headway of 2 min); - Peak hours (Headway of 30 s, 8 am to 12 am and 4 pm to 8 pm).	**1. Low capacity of just 28 passengers per pod.** - The hyperloop is expected to carry 3360 passengers during peak hours and 840 passengers during off-peak hours; - Capacity of 36,120 passengers per day; - Even if the hyperloop were affordable to all, only 17.5 percent of the existing passengers (205,480) that commute between the two cities are likely to have access to it; - Between 56 and 90% of the hyperloop capacity may remain unutilised. **2. Headways of 30 s and 2 min seem unrealistic for safety reasons and loading and unloading of passengers and baggage. Eighty seconds may be needed for the peak.** - Headway proposed by VHO already provides a low capacity, so much longer headway would further reduce the capacity of carrying passengers per day.
Score		

Table 9. Summary of the most important negatives and positives of the Mumbai to Pune hyperloop in terms of its economic factors.

Economic Factors	Positive Effects	Negative Effects
Construction and operational cost of Mumbai to Pune hyperloop		**1. High estimated costs.** Hyperloop is expected to cost a minimum of USD 139 million per km (Total cost: USD 16,680 million). **2. Actual real-life costs are bound to exceed the expected costs.** - A section of the corridor (6 km) requires tunnelling; - Construction of the hyperloop from BKC Mumbai to Navi Mumbai is to be underground. **3. The funding of this projects is based on a PPP with Virgin Hyperloop One** - India does not have the funds to afford the hyperloop project on its own; - Even if India funds 10 percent of the project, it will absorb infrastructure funds which are already poorly allocated towards public transport such as for BRTs and metros. **4. High operational costs.** **5. Loss of public goodwill and political cost of development of other essential infrastructure.** - Metro construction costs are lower than that of a hyperloop by 3 to 8 times and metros have a carrying capacity of 75,000 passengers per hour in one direction; - With USD 16,680 million thousands of kilometres of BRT infrastructure could be constructed, which has a carrying capacity of 25,000 passengers per hour in one direction.
Score	No positive effects	

Table 10. Summary of the most important negatives and positives of the Mumbai to Pune hyperloop in terms of its human, technical and environmental factors.

	Positive Effects	Negative Effects
Human factors: Affordability, equity and impact on lifestyle		**1. Fare is expected to be similar to flying.** - Based on the population of Mumbai and Pune and their income groups, only 4.9 to 6.2 percent of population is likely to afford the hyperloop. **2. Low modal shift from existing modes of transport.**
Score		
Technical factors: Safety and comfort		**1. Still in its testing phase, so there are various technical aspects of the hyperloop that are questionable.** **2. No windows** - Claustrophobic; - Passengers will miss out on the landscape along the route. This will create a greater disconnect between passengers and nature.
Score		
Environmental factors		**1. No countering effect on automobiles.** - The total possible shift of passengers from the car (146,000) by the proposed Mumbai to Pune hyperloop is expected to be 1 to 8%; - It is expected to have a negligible or no effect on mitigating the increased number of cars and, hence, carbon emissions. **2. Land clearing for the 6 km stretch of Western Ghats tunnelling may impact the local environment.** - Natural land is reduced and fragmented; -Cutting of trees. **3. Proposed terminals at Navi Mumbai and Wakad are not well integrated with public transport.** - May attract parking lots, cause traffic noise; - Visual intrusion and opportunity costs.
Score	No positive effects	

Table 11. Summary of the most important negatives and positives of the Mumbai to Pune hyperloop in terms its urban planning implications.

Urban Planning	Positive Effects	Negative Effects
Regional level	**1. It is expected to improve the status and competitiveness at a regional level.** - Enhanced economic potential and positive locational factors. **2. It may elevate an area's position in the national urban hierarchy.**	**1. Higher cost of living.** - Gentrification, certain people may move to less expensive unconnected cities. **2. Unconnected cities may face the challenge of a lowered position in the urban hierarchy.**
Urban level	**1. May reinforce urban development on an urban level.** - Drives growth; - Accelerates the rate of urban expansion. **2. May improve the overall image of the city.**	**1. Decrease in cultivated land.** **2. May be poorly integrated with rest of the city planning.** - Contraction of space will not be uniform throughout the city; - Imbalance between the city and its hinterlands. **3. Only the area around the terminals will receive intense planning while other parts of the city may weaken. This will result in increased value around the station area.**

Table 11. *Cont.*

Station level	**1. May induce catalyst effect.** **Hyperloop's impact at station level is mostly generative. It may show significant economic spinoffs and extensive redevelopment.** - This may improve the status and modernity of the station area. **2. High-rise and dense development.**	**1. The value of land and rent may increase. This may result in low affordable housing and displacement of low-income groups.** **2. Barrier effect.** **3. Possible increase of noise and crime in station area.** **4. Increase in government subsidies and opportunity costs due to foregone services caused by enormous expenditure for hyperloop.**
Score		

Source: Tables 8–12—Elaborated and extended by authors based on previous data.

Table 12. Summary of the most important negatives and positives of the Mumbai to Pune hyperloop in terms of its transport implications.

Transport Implications	Positive Effects	Negative Effects
Terminal 1: BKC Mumbai The proposed terminal is centrally located in Mumbai.	**1. To be constructed in existing metro station infrastructure.** **2. Well integrated with metro and bus.** - Saves terminal cost, time and ease of integration with other modes of transport.	
Terminal 2: Navi Mumbai The proposed terminal is centrally located in Navi Mumbai.	**1. To be constructed in existing airport infrastructure.** (Under construction)	**1. Bus stations and rail stations located 4 km from the proposed terminal.** - Poor performance; - Poor integration of public transport and easier for car accessibility; - Low passenger volume.
Terminal 3: Wakad The proposed terminal is located on the periphery of Wakad.		**1. Challenge to create additional capacity for hyperloop station in the existing urban fabric.** **2. Requirement of new infrastructure.** - High cost associated with land acquisition; - High cost and disruption involved. **3. No metro access within 5 km radius from the proposed hyperloop terminal and nearest bus station is 700 m.** - Poor performance; - Difficult public transport, more expensive and easier for car accessibility; - Low passenger volume.
Score		

Tables 8–12 summarise the positive and negative effects of the proposed Mumbai to Pune hyperloop based on the findings in this research. Each table is briefly discussed below.

Assessment of Mumbai to Pune corridor as a potential corridor for a hyperloop system: Loo and Huang [88] study and compare the location of HSR stations in mainland China and Europe. The paper discusses the importance of station locations for high-speed ground transportation and its role and implications in the process of city evolution. The authors state that cities are living structures and that station locations need to be carefully considered in relation to urban node clusters to bring local opportunities and to act as a sprinkler to irrigate the regional economy [88]. Mumbai and Pune are two important growing cities of India with high economic productivity. The cities are a part of the same megaregion, the western part of Maharashtra and their intercity connection is one of the most essential in the country. Around 75 million travellers commute between the two cities annually. Due to poor intercity connections through public transport, road travel by car is the preferred travel mode. However, the distance between the two cities is less than 500 km, which may be a disadvantage for hyperloop. Nevertheless, since the proposed route's physical nature restricts the hyperloop's potential speed to 500 km/h, the distance factor is less critical.

Corridors and terminals of Mumbai to Pune hyperloop: It is imperative to carefully plan and balance the integration of stations within the host city, especially in existing activity clusters without creating urban crowding and congestion. However, stations need to be close to existing activity centres in order to avoid ghost towns [88]. Mumbai and Navi Mumbai's proposed terminal locations are within their city centres or existing activity clusters. In contrast, the proposed location of Wakad is on the periphery of the city. For Mumbai and Navi Mumbai, the proposed terminals may strengthen the commercial and business centre's surrounding area. This will offer significant potential for urban revitalisation compared to Wakad. However, the proposed Wakad terminal location may lead to the redevelopment of underutilised regions on its periphery and define its terminal location as a new crucial urban centre.

Travel time, capacity and efficiency of Mumbai to Pune hyperloop: The restricted speed would reduce the time saved on the proposed hyperloop compared to its commercial claim. Indian metros, which have a security scanning provision but no baggage handling, have a minimum headway of 2 min. Therefore, with baggage handling, even a 2-min headway seems unrealistic.

Based on the headway set by VHO, the number of passengers the hyperloop could theoretically carry per day is 36,120, if it runs at full capacity with every departure. However, even after the hyperloop becomes operational and passengers shift from other modes of transport to it, 56 to 90% of the hyperloop may remain unutilised, which is enormously lower than BRT or metro. This is because the rate required to fill the hyperloop's capacity through modal shifts is unrealistic due to its high fare. Further, even if the proposed hyperloop is affordable to all, only about 17.5% of the total existing daily passengers along the Mumbai to Pune corridor could travel by the hyperloop. With the increase in headway, the carrying capacity's realistic numbers are bound to be much lower.

Energy consumption of Mumbai to Pune hyperloop: Due to the tropical climate, the Mumbai to Pune corridor receives an abundance of sunlight and rainfall throughout the year. Therefore, it should be cheaper and relatively energy-efficient to use solar and water energy to power the electrical grid.

Construction and operational costs: As the minimum cost of constructing the proposed Mumbai to Pune hyperloop is USD 139 million per km, the real-life costs are expected to be much higher. Also, the feasibility reports of this project have not been made public; therefore, the amount of funds invested in the project is uncertain. It is also clear that India will not be able to afford this project on its own, given the current allocation of funds for transportation infrastructure. However, with the funds that could potentially be invested in this project, thousands of kilometres of BRT or metro infrastructure could be constructed in several Indian cities. Therefore, it is imperative to rethink investments in such advanced projects, given the existing transportation challenges. Also, it is essential to review India's allocation of funds in transportation infrastructure, which prioritises roads and highways over public transport.

Affordability, equity and impact on lifestyle: This hyperloop may be expected to have a similar fare to that of air travel. Given the population's income groups, a very tiny section of Mumbai and Pune's population may afford the hyperloop (4.9 to 6.2%). Furthermore, the proposed hyperloop is expected to have a very small potential to handle new induced trips.

Safety and comfort: The proposed hyperloop has various technical, safety and comfort factors that are questionable (see Table 2). The hyperloop tube is expected to protect the pods from the abundance of sunlight and rainfall throughout the year, preventing delays and breakdowns. However, the proposed corridor has an attractive natural landscape, which the passengers would be deprived of witnessing and connecting with.

Environment: There are many environmental issues linked with the Mumbai to Pune hyperloop. Even after passengers shift from cars and airlines, around 90–97% of passengers may remain on existing modes and hardly impact existing roadway congestion, fuel consumption and carbon emissions. Also, the section of the Western Ghats area lying on the proposed route will require tunnelling, land-clearing and cutting trees, impacting the local physical environment. Natural land will be reduced following the potential increase in socio-economic activities after the hyperloop's construction, indirectly affecting the surrounding agricultural land and wildlife [10]. Further, the proposed terminals at Waked and Navi Mumbai may attract parking lots if measures are not taken to integrate them with other public transport. The hyperloop may also cause noise and visual intrusion if not strategically placed in the urban fabric, limiting the possible use of space around the proposed hyperloop corridor. Therefore, it is imperative to integrate and plan the terminals well [8].

Regional level: The proposed hyperloop brings the cities of Mumbai and Pune together, driving development effects. However, these effects would result in a more considerable disparity with the unconnected cities along the corridor, namely, Panvel, Khandala, Lonavala and Talegaon. However, the proposed hyperloop's restricted speed of 500 km/h may allow provision of intermediate terminals lying in these cities on the corridor. Mumbai, Navi Mumbai and Pune connected to the hyperloop are expected to grow differently. Mumbai, which is already a dominant city, may become more competitive. On the other hand, Pune and Navi Mumbai may have more significant development impacts such as an improved location factor, attracting business activities and increased tourism.

Urban Level: The station areas of the Mumbai to Pune hyperloop are expected to gain new facilities, attract offices, commercial areas, cultural establishments, public facilities, housing and public spaces. However, there are various challenges involved, such as an imbalance between the city and its hinterland that may cause gentrification around station areas, resulting in the displacement of low-income households and which may give further rise to urban sprawl. It may facilitate polarisation between the station area and other regions of the city and result in segregation.

Micro Level: The primary zones of BKC Mumbai, Navi Mumbai and Wakad terminals may achieve improved status, resulting in higher land prices, high-grade offices, and residential functions. This may facilitate high-rise buildings and other dense development. These terminals' secondary zones may have similar effects as the primary zone, although less intense. Their tertiary zones are less likely to see development. Among the challenges, the hyperloop station area is expected to cause institutional barriers, physical "barrier effects" and development of a separate "island".

Integration between hyperloop and urban transport networks: The proposed terminal of BKC Mumbai is centrally located on a BKC metro station which is under-construction, so well-integrated with existing public transport. This will save the passengers time to reach the station and access an already available metro infrastructure, saving terminal costs. The proposed terminal of Navi Mumbai lies within the existing infrastructure of an international airport, also under construction. The integration of the proposed terminal location is low and may depend on personal vehicles for access, resulting in low passenger volume. The proposed terminal of Wakad lies on the outskirts of Pune. The terminal would require new infrastructure and additional space in the existing urban fabric, resulting in disruption, costs associated with land acquisition and extra terminal costs.

Since each variable mentioned above has only or primarily negatives, it is concluded that the proposed Mumbai to Pune hyperloop has a high-risk profile. Therefore, this project's construction needs to be reconsidered, as it is expected to cause more loss than benefits.

4. Lessons for the Mumbai to Pune Intercity Connection

Hyperloop's uncertain nature adds to the risk profile of its construction. This section translates hyperloop's challenges into three significant recommendations.

4.1. Important Precondition for the Mumbai to Pune Hyperloop

The Mumbai to Pune hyperloop's challenges require serious contemplation, revolving significantly around the fact that the hyperloop needs to reach product maturity. Therefore, waiting for the technology to mature and gaining experience is a logical outcome of the research undertaken here, which is explained further below.

Wait for the technology to mature and gain experience: Operational HS ground transportation modes such as HSR and Maglevs are the result of decades of development. For example, the French TGV was proposed in 1960, while it only became operational from 1981 onwards [89]. Therefore, developing a more complex transport system like the hyperloop may take considerable time to mature and become functional. Still, there may be no assurance of its success. For example, "Concorde," a supersonic aircraft, took roughly 3 h to fly between New York and London, compared to a conventional airline which took up to 8 h. Nevertheless, after 15 years of development and 27 years of commercial operation, in 2003, it was decommissioned. This was due to various reasons such as safety, low capacity, high cost of operation, maintenance and energy consumption, and a fatal crash in 2000 [89].

Lessons extracted from this research show that the hyperloop's risk profile is still very high to experiment within India, which is already struggling with numerous existing urban mobility challenges. India is not ready for such advanced technology and may make a costly mistake by pursuing the project at this point. It is imperative to wait for the technology to mature and gain experience with it and even then, hyperloop would still require detailed evaluation for its relevance to India.

4.2. Alternative Solutions to Enhance the Intercity Connection between Mumbai and Pune

India has one of the largest transport sectors globally; however, it faces numerous challenges [90]. A glimpse of this can be seen in the existing transport connection between Mumbai and Pune. There is a definite need to modernise the existing transport infrastructure with good physical connectivity and energy-efficient technology. This section filters the most important preconditions for strengthening Mumbai and Pune's intercity connection by enhancing and improving its ability to carry the growing demand of passengers through alternatives.

4.2.1. Public Expenditure Alternatives to Hyperloop

Public transportation forms a core mobility offer of an agglomeration. Therefore, it needs to be smart, sustainable, convenient, comfortable, competitive with cars and motorcycles and, most importantly, affordable [83]. There is a critical need to improve and advance the current public transport connecting Mumbai to Pune. With all its challenges, mass transit such as rail and BRT offer sustainable solutions to reducing traffic and congestion and ameliorating environmental degradation [83].

Rail travel: Years of under-investment in rail travel in India makes travelling by rail between Mumbai and Pune inefficient, unreliable and dangerous. Additionally, trains are old, poorly designed, inadequately maintained and slow [91]. Therefore, it is necessary to improve and upgrade the existing railway systems through investment, keeping in mind the high volume of passenger traffic, enabling them to work at peak efficiency [91,92].

BRT intercity bus: The existing bus service between Mumbai and Pune can be improved by replacing it with an intercity BRT line. This can deliver attractive service levels at a very low cost compared to other public transport such as heavy rail or metro. However, it is necessary to ensure it includes key elements—dedicated, physically protected right-of-way, pre-board fare collection and special branding. These elements decrease travel time and increase ridership. This can be seen in examples around the world, such as Metrobus in Istanbul and EmXBRT in Eugene (USA). Metrobus increased passengers by 105% and ensured a travel time reduction of 65% in its area of operation. In Eugene, EmXBRT attracted 74% more passengers [93].

The BRT bus would stop at the four intermediate cities lying on the MPE—Panvel, Khandala, Lonavala and Talegaon—which the proposed hyperloop will ignore. These cities should have station-like bus stops with ticketing systems on the platform, as well as real-time information and signal priority at intersections along the entire corridor.

4.2.2. Improve the Existing Transport Infrastructure and Experience

Growth in Indian cities has increased travel demand; however, public transport infrastructure and positive user experience are still lagging [91,94]. There are various solutions to this such as GPS tracking and availability of real time passenger information, WIFI, smart stations and integrated ticketing with the existing modes of transport. According to Kohli [90], India's current transportation requires new technology to replace old infrastructure, technology and rolling stock.

It is essential to improve the user's experience through good integration of existing transport modes. The intercity railways need to be well integrated with city metros and BRTs. Thus, it is also necessary to expand metro systems and introduce genuine BRT within cities with integrated routing, timetable matching and ticketing [91]. Also, mobile applications can deliver real-time passenger information [95].

The inadequate facilities for pedestrians and cyclists in Indian cities force them to share space with motorised vehicles. Therefore, facilities for pedestrians and cyclists (separate sidewalks and cycle lanes) are a significant requirement. This will increase safety and avoid conflict on roads and enhance access to public transport stops [91].

User experience can be enhanced through better and stricter enforcement of traffic laws and regulations, ensuring safety for pedestrians and cyclists. New development should take place only if it promotes walking, cycling and public transport. Stricter rules on motor vehicle noise, such as horn use restriction, would reduce the road noise immensely [91].

First- and last-mile connectivity is essential, enabling accessibility to mass transit networks to a large proportion of urban populations. Therefore, it is vital to have solutions that bridge the gap [95]. For non- or lightly-motorised travellers, the provision of e-scooters [96] and shared bikes/e-bikes, can be a good alternative [97], providing cheap, healthy and low-carbon lifestyles.

4.2.3. Rethink Government Funding in Public Transport

The Indian government focuses on the private-motorised elite while largely ignoring the needs of non-motorised and public-motorised travellers. At the same time, congestion is bound to get worse in the coming years due to city densities and the impossibility of endlessly expanding road supply, causing low-income populations to suffer most [91]. Therefore, there is an urgent requirement to rethink government funding allocation, prioritising public transport such as mass transit and non-motorised needs.

If the total government investment funds for mass transit and roadways in Figure 10 were swapped, most of the funds would go to mass transit and only 10% to roadways. For a more precise picture, Table 13 compares the cost of constructing mass transit (BRT and metro) in India and compares it to its highway projects. The average cost of construction of 1 km of highway (4 lanes) is around USD 27 million (USD 2017) [98].

Table 13. Cost of constructing mass transit in India compared to that of highways.

Mode/City	Cost of Construction (USD Million 2017 per km)	Kilometers of Construction Possible with the Total Funds Allocated by the Government for Roadway and Highways (USD 12.4 Billion)	Kilometers of Construction Possible with the Total Funds Allocated by the Government for Mass Transit (USD 2.6 Billion)
Highways	USD 27	459 km	96 km 363 km less than middle column.
Mumbai metro (in 2011)	USD 19 1.4 times less than the cost of 4-lane highway construction.	653 km	137 km 516 km less than middle column.
Delhi BRT (in 2010)	USD 2 13.5 times less than the cost of 4-lane highway construction.	6200 km	1300 km 4900 km less than middle column.

Source: Elaborated and extended by authors based on data from previous sections.

It is clear from Table 13 that the metro's cost in Mumbai is 1.4 times lower than that of highways. With the government funds for 459 km of highways, the construction of 653 km of metro in Mumbai and 6200 km of BRT (in Delhi) could occur. Additionally, if roadways swap funds with mass transit, it would decrease new highways by 363 km. On the other hand, BRTs and metros may increase by 4900 km and 516 km, respectively. Therefore, just swapping the existing funds of mass transit versus highways could provide much greater network lengths of high-capacity public transport for a wider range of income groups.

4.3. Important Preconditions for a Hyperloop Proposal in India Assuming Successful Experience Globally

The Indian sub-continent has the largest railway network and the highest rail passenger traffic globally. However, India does not possess the technology for HS ground transportation nor policies to implement it. Therefore, it may be difficult for India to propose HS ground transportation with no implementation strategies [99]. This section presents preconditions to prepare for advanced technology like the hyperloop in the future, assuming its success in other parts of the world, which is still far from tested.

Critical evaluation of hyperloop experience in other parts of the world: Before proposing a technology like a hyperloop, it is essential to critically evaluate and study its experience in other regions globally and educate those involved regarding the technology [99]. This will help answer questions regarding hyperloop's expected behaviour in a specific country.

The Indian government needs to focus on ways to educate itself regarding such technology before pursuing it. Laxity in evaluating such technologies due to lack of care in research, knowledge and unclear impacts may result in harmful side effects, possibly including mass deaths. For example, in 1990 Chinese engineers were sent to France and Japan to learn HSR technology. In 2008, through independent innovation, China committed to developing a new generation Chinese railway system with speeds up to 380 km/h [99]. Similarly, after any hyperloop success globally, India could fund sending engineers and experts for detailed study to educate themselves, study the system in different regions, and carefully evaluate and analyse the hyperloop in terms of its actual physical planning, technical, human, urban planning and transport implications in the Indian context. India needs to change its current approach for pursuing projects, driven by status and commercial claims. To be seriously considered, hyperloop would need to fulfil basic requirements, such as higher passenger carrying capacity for the proposed corridor, no threats or safety issues and affordability for a high proportion of the population. But this still would always need to be balanced against local mobility needs.

Critical evaluation of hyperloop's funding in India: Critical evaluation of funding is another necessary precondition required before proposing hyperloop in India. This research demonstrates that hyperloop's construction cost is not viable, given Mumbai's and Pune's socio-economic profile. We also suggest the importance of funding BRT and metro systems instead (as well as enhanced conditions for non-motorised modes), which are already beneficial, have lower construction costs, higher capacity and are affordable to a much higher proportion of the population. Analysing the costs of projects such as the hyperloop against other existing, less costly alternatives permits comparisons and their pros and cons, narrowing down the most optimal option for the current situation.

Since the 1960s, India has been considering upgrading existing trains speeds to 160 km/h [100] and since 2000, India has intended to usher in high-speed ground transportation [99]. With just one train running at 160 km/h, with constant revision of the deadline for others and no active high-speed ground transportation, India has failed to achieve either goal. Also, the current simultaneous planning of new high-speed ground transportation with the upgrading and inclusion of trains at 160–200 km/h on the same route, creates competition and chaos [100]. Therefore, India needs to take one reasonable step at a time. To achieve this, it is imperative to have a clear funding plan and schemes to improve its current transport infrastructure before investing in new advanced technologies while overlooking current challenges.

Also, India's budget needs to reflect a national policy of high-speed ground transportation along with a clear plan for railway expansion and speed upgrades. China's example successfully anchors high-speed ground transportation in its national objectives, achieving multiple goals. Goyal [99] highlights this in his paper as the 'Seven Pillars of HSR success in China' (pp. 156). From 1997 to 2004, China's express train speed gradually increased from 140 to 200 km/h. It also planned its railway expansion to achieve 120,000 km by 2020. Of this expansion, 12,000 km were to be Dedicated Passenger Lines between major provincial centres (target speed of 250–300 km/h). Beyond completing this scheme, a fast passenger railway network (target speed of more than 200 km/h) totalling more than another 12,000 km was to be established [99]. By July 2020, China had achieved all its targets mentioned above with 141,400 km of railway tracks [101]. Furthermore, by the end of 2021, just the length of HSR in China reached 40,000 km [88].

Similarly, India could develop a scheme that clearly lays out the existing challenges, mobility needs, and ways to overcome them in a limited time frame. This would be the performance benchmark; only after the completion of this goal should India think about futuristic technologies. The "bottom line" here is should India adopt futuristic transportation such as hyperloop in preference to already beleaguered mass transit such as BRT and metro? Or instead, should it invest the funding for 120 km of hyperloop in, for example, thousands of kilometres of BRT or hundreds of kilometres of new metro? Answering such questions democratically involves some form of national debate.

Corridor selection, integration and development effects: The detailed evaluation of experience around the world enables an understanding and definition of criteria for the selection of hyperloop corridors most likely to extract maximum benefits through the best capacity utilisation [83]. The defined criteria should be adhered to as the foundation of building the proposal and avoiding diminution of potential benefits from advanced transportation systems.

Hyperloop terminals are also critical and need to be embedded into the existing urban fabric while linked with current public transport modes through physical connections, integrated ticketing and matching timetables. Such matters are crucial for increasing passenger volume, maximising the serviced region/spatial penetration, reducing transfer resistance and bringing passengers to access points of other modes. Additionally, good terminal locations will avoid disorderly competition, stimulate cooperation among operators and improve urban development potential.

It is also essential to check the viability of hyperloop's potential development effects by examining the urban development effects of other HSR or intercity BRT. For example, the

Mumbai–Pune hyperloop has a limit of three intermediate stations. The major drawback of this is the development imbalance which may be created. By contrast, BRT and HSR can incorporate more stations and better distribute any urban development benefits.

Technology acquisition and speed: Before proposing technologies such as hyperloop, it is essential to address such questions as: Is India ready for such advanced technology and speed? Can such a system be maintained and serviced with local resources? To answer this, it is essential to understand the complexity of advanced transportation technology. This overview, especially regarding construction and fare costs, clearly show that India is not ready for such a technology in the current situation. Goyal [99] states that, "the current technology base does not permit the indigenous introduction of trains running even speeds of 200 km/h. Would the import of HSR technology on the 'buy off the shelf' route be most optimal?" (p. 159).

Due to the high-profile nature of projects such as hyperloop, countries may rush towards finalising them based on overestimated ridership and socio-economic benefits, and underestimated costs without detailed analysis. Technology transfer and localisation is vital before adopting HS ground transportation. Countries that adopted HS ground transportation, such as HSR without this, are facing operational, maintenance and financial troubles. Some examples are HSR projects in Taiwan and the Netherlands, which faced challenges due to the absence of technology, assimilation and localisation and particularly, inaccurate ridership forecasts, financial distress, mechanical and software deficiencies and sustainability issues [99].

Advanced transportation has highly complex technology, requiring substantial knowledge and leading-edge technical skill. The technologies often involve high financial exposure; so to reduce that, the system requirements in terms of safety, technology and operations will require localisation. India uses the buy and operate model [99], however, hyperloop would require localisation and cannot be left solely in third-party hands. At present, India is not ready for such technology, nor can it be maintained and serviced with local resources without first localising the technology.

Public consultation and surveys: The viability of new infrastructure depends on the public's acceptance of the mode [83]. For a mega-project such as hyperloop, where billions of dollars may be invested from government funds, the vital precondition of public consultation is necessary [99], where information is openly shared. Through this, communities can share their view on current mobility needs, which should ideally be how governments set their transportation infrastructure spending priorities. Several platforms talk about feasibility reports for the Mumbai to Pune hyperloop however, none are available to the public [102–104]. This shrouds in doubt the basis of the feasibility reports, as the hyperloop has had only a few high-profile test runs, including just one with humans onboard. Virgin Hyperloop, which carried the human onboard test run (speed of just 170 km/h), earlier in 2022, laid off almost half its staff, announcing a switch from a human to a cargo focus. This raises doubts about the system and leads to speculation whether its technical challenges were underestimated. Therefore, the risk factor of hyperloop technology is a warning to avoid wasting valuable money that could be used for public transit or, perhaps worse, the cost of human life. It is, thus, crucial to rely on real available mobility solutions in favour of, for and by the people [105].

In this regard, there is little or no broader awareness of the pros and cons of the system, nor public consent regarding its controversial costs, which will be later recovered through high or less affordable fares than other conventional trains [99]. This will leave benefits to accrue only to minority high-income groups.

As this paper has explained, various other challenges are also involved with the hyperloop, such as environmental impact, physical planning, land use and urban development, which communities may question. Therefore, consultation procedures are needed which can include citizen panels, formal, open hearings and surveys as part of an intense and bona fide public consultation process [99].

5. Conclusions

This review paper was based on answering four guiding questions identified in the introduction regarding the viability and applicability of a hyperloop corridor between Mumbai and Pune. Summary answers to these questions are as follows.

(1) The first question asked about the reasons for choosing the Mumbai to Pune hyperloop corridor. At present, 75 million people travel this corridor each year. However, the hyperloop has a much lower capacity which highlights its inability to handle any induced trips that might occur. Furthermore, given the socio-economic conditions, a very small proportion of the population, or indeed perhaps only "the elite" might afford the system. India faces immense current mobility challenges. Even if it partly invests in the hyperloop project, which it cannot finance independently, it will suffer loss of investment funds that are essential for other public transport mobility needs, which are already underfunded compared to highways. The cost of funding the hyperloop could support construction of hundreds of kilometres of metros and thousands of kilometres of BRT within Indian cities.

(2) The second question enquired about the positives and the negatives of the hyperloop technology. The negative impacts of this technology weigh heavier than the positives. One of the many drawbacks of the proposed corridor is its route. A major selling point of the hyperloop, its speed of 1200 km/h, cannot be fulfilled, but rather, due to topography and other factors, the likely speed would be closer to 500 km/h. Left out of publicly available information is a very likely higher construction cost, adverse or at least problematic or inconsistent effects on land use intensification and promotion of urban sprawl. One of the few positive points of the proposed hyperloop is the region's tropical climate and sunlight, which, through solar power, could be used for hyperloop's energy requirement. However, the paper reveals that in every key aspect, the project has a high-risk profile and its construction should be reconsidered.

(3) The third question seeks an answer to the preconditions necessary to pursue a hyperloop technology. This paper revealed three major preconditions necessary for a hyperloop to be considered. First and most important, hyperloop technology needs to mature and gain experience. A costly, advanced technology is not the answer to India's current mobility challenges, so they need to be solved through other means. Transport infrastructure needs to be improved along with user experience through first and last-mile connectivity, proper integration of modes and land use, fit-for-purpose choice of technologies, and at the other end of sophistication, simply more high-quality dedicated footpaths/lanes for pedestrians and cyclists. The government's allocation of funds needs to be reconsidered whereby they invest more in projects such as BRTs and metros and lessen the distribution of funds to high-capacity roads. Finally, before proposing a technology such as hyperloop in India, should it be successful elsewhere, it still needs to be critically and openly evaluated for its wider implications and, most importantly, costs.

(4) The fourth and last question investigates transport planning and urban and regional planning solutions for the projected effects of a hyperloop between Mumbai and Pune. Governments at all levels in India are the main players implementing transport strategies that help resolve current mobility challenges, as well as potential challenges faced in constructing any hyperloop. Transport planning solutions must focus on expanding mass transit (BRT, metro) and strengthening and modernising the existing public transport, through better infrastructure, technology and rolling stock to provide good physical connectivity and energy-efficient technology. Such modes have standalone value wherever implemented in India. Regarding hyperloop, integrating such new systems could assist in better first- and last-mile connectivity. The inclusion of hyperloop terminals into existing urban fabrics would need to link with current public transport modes through physical connections, integrated ticketing and matching timetables to ensure maximum passenger volumes. This would also expand the region served, reduce transfer resistance and bring passengers to the access points of other

modes, thus increasing hyperloop's spatial penetration. It would also be necessary to maximise pedestrian and cyclist access to hyperloop through much better, safer infrastructure, stricter traffic laws and provision of e-scooters and shared regular bikes and e-bikes.

Hyperloop, through HSR experience, has been shown likely to have a range of urban and regional planning impacts, depending on how and where any system is implemented. These effects can be summarised briefly mainly according to the distance from the terminal and the overall urban context of the terminal's location.

The station areas of the Mumbai to Pune hyperloop are expected to gain new facilities, attract offices, commercial areas, cultural establishments, public facilities, housing and public spaces. The primary zones of BKC Mumbai, Navi Mumbai and Wakad terminals may witness dense development and a significant number of effects, their secondary zones may have less intense effects, while their tertiary zones are less likely to see development. However, these areas require thorough research to avoid the creation of institutional barriers, physical "barrier effects" and development of separate "islands". If they were to become "hyperloop cities", a balance would need to be established between Mumbai and Pune and its hinterland to prevent the development of gentrification around station areas, increased urban sprawl, and possibly greater polarisation and segregation in existing urban patterns.

At a regional level, hyperloop would likely drive development effects bringing the cities of Mumbai and Pune together. However, these effects would result in a greater disparity between the unconnected cities along the corridor; Panvel, Khandala, Lonavala and Talegaon. This could be prevented through the provision of intermediate terminals in these cities, though it would slow the service. Mumbai, Navi Mumbai and Pune would be expected to grow differently; Mumbai, which is already a dominant city, may become more competitive, while Pune and Navi Mumbai may have more significant development impacts such as an improved location advantage, attracting business activities and increased tourism.

In summary, even though hyperloop technology for passenger transport is fascinating and may have its benefits, only time will tell if Elon Musk's vision will be a success and assist in attaining sustainability goals at a local, regional and global level. At present, to use a relevant analogy, it may be more of a "pipe dream". This seems to be especially the case in India due to (a) the country's many other urgent mobility needs which require significant funding and which can be addressed with conventional technologies and (b) its current level of wealth which may undermine potential hyperloop patronage. These conclusions are drawn in the absence of any commercially operating passenger hyperloop service anywhere in the world, which is an unavoidable limitation of the study. However, the work is based upon what the authors consider to be the best available relevant information at this time. Should a commercial passenger hyperloop service be established somewhere in the future, then such conclusions could be revisited.

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