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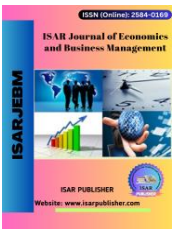

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Improving the transport system of India (illustrated by use of passenger transportation) through implementation of transport and infrastructure solutions by Unitsky String Technologies

Anatoly Unitsky[1], Alexey Klimkov[2*], Ekaterina Vlasovets[3], Olga Kulik[4]

[1]PhD in Transport; General designer Unitsky String Technologies Inc., Astroengineering technologies Inc., Minsk, Belarus

[2]PhD in Economics; Head of R&D department Unitsky String Technologies Inc., Minsk, Belarus

[3]Head of Marketing and Analytics Department Unitsky String Technologies Inc., Minsk, Belarus

[4]Lead Analyst of the Marketing and Analytics Department Unitsky String Technologies Inc., Minsk, Belarus.

***Corresponding Author**
Alexey Klimkov

PhD in Economics; Head of R&D department Unitsky String Technologies Inc., Minsk, Belarus.

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Abstract: Despite the growth of the Indian economy at the present stage, there are a number of significant challenges in the country`s transport sector. This research, based on a review of innovative Unitsky String technology advantages, presents 4 conceptual directions for integrating solutions into India's existing transport infrastructure in terms of passenger transportation. Additionally, it outlines the socio-economic impact that the implementation of these solutions could bring to the country and its regions.

Keywords: Transport system, passenger transportation, transport and infrastructure solutions, uST, socio-economic impact, GDP growth, ecological problems.

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Introduction

India is one of the growing economy countries, the population of which increases annually by an average of more than 1 % and has already surpassed China in this indicator (The World Bank Group, 2024). The country is rapidly developing the transport industry; in particular, India is one of the heavy-loaded countries in the world in terms of traffic. Thus, the automotive industry of this country back in 2017 became the fourth largest in the world (Statista, 2024).

At the same time, with the growth of the economy and population in the country, problems related to the functioning of the transport industry are becoming more and more urgent.

One of the problems for the transport system of India is the increase in the number of vehicles and road traffic (on average at a rate of 7–10 % per year) (Patel & Parekh, 2017), in connection with which the modernization of the transport network (increasing the length of paved roads, improving their quality, building new roads in remote/hard-to-reach areas) cannot comply with such growth rates.

In addition, ecology and environmental pollution constitute particularly harsh problem to the country's economy. According to (Annual Update, 2024), India ranks first among Asian countries in terms of environmental pollution, whereby more than 1 million people die every year due to diseases caused by pollution. At the same time, the growing number of cars as a whole provokes further environmental pollution: the share of "clean" electric vehicles BEV ("Battery Electric Vehicle") in India's market at the end of a record 2022 accounted for only 1.3 % (Auto Punditz, 2022). According to (Patel & Parekh, 2017), road transport emissions alone account for about 72 % of total air pollution in Delhi, while fossil fuel burning accounts for more than 80 % of carbon dioxide emissions in the national capital city. In addition, high levels of traffic congestion, limited multimodal integration, poor quality of public transport systems and sidewalks, lack of bicycle tracks lead to increased levels of road emissions and noise pollution in the country (Energy and resources institute, 2020).

Thus, the country needs scientific and technical/innovative solutions for the transport industry, the implementation of which will allow: a) to improve the environmental situation with ensuring an increase in labor productivity, quality, speed of transportation, appropriate infrastructure security, maintaining the availability of passenger-and-freight traffic; b) act as a transport industry driver for the development of the national economy.

Hypothesis

In India, the innovative technologies and solutions by Unitsky String Technologies (uST) are relevant and can be recommended for implementation in the current transport system

(in relation to this study – in passenger transportation) and have a significant socio-economic effect.

Materials and Methods

This article uses theoretical research methods (analysis, synthesis, classification, deduction, induction, generalization) and statistical methods of data analysis (method of contrast of means, factor analysis), through which the dynamics of development of Indian economy at the present stage (1980–2022) is substantiated.

Open scientific sources, as well as official Internet-resources of various organizations, primarily Indian, were used for this study.

Based on the justification of the benefits of uST technology for the transport infrastructure industry in India, 4 conceptual examples of integrating uST solutions (in terms of passenger transport) are proposed, viz:

- transport link between two operating terminals (Chhatrapati Shivaji International Airport (Mumbai));

- connecting transport link between airports and the existing transport infrastructure of urban agglomerations;

- integration into the existing public transport system of the city of Warangal;

- tourism sector of India (a route in the state of Goa).

Each example contains a justification of the socio-economic effect. Similarly, for India as a whole.

Research results

Development of Indian economy at the present stage (briefly).

Below is the dynamics of the development of India's economy since 1980 in comparison with the leading world powers – the United States and China – in terms of GDP at current prices.

In particular, based on Figure 1, it follows that the contribution of India's economy to global GDP in the 21st century is constantly growing (from a value of 1.38 % in 2000 to 3.35 % in 2022). The average annual GDP growth rate (in current prices) reached its peak in the period 2000–2010 (on average more than 25 % per year), while over the past 5 years it reached and exceeded, in the pandemic (and post-pandemic) 2020–2022 years, the same growth rates of China (Figure 2).

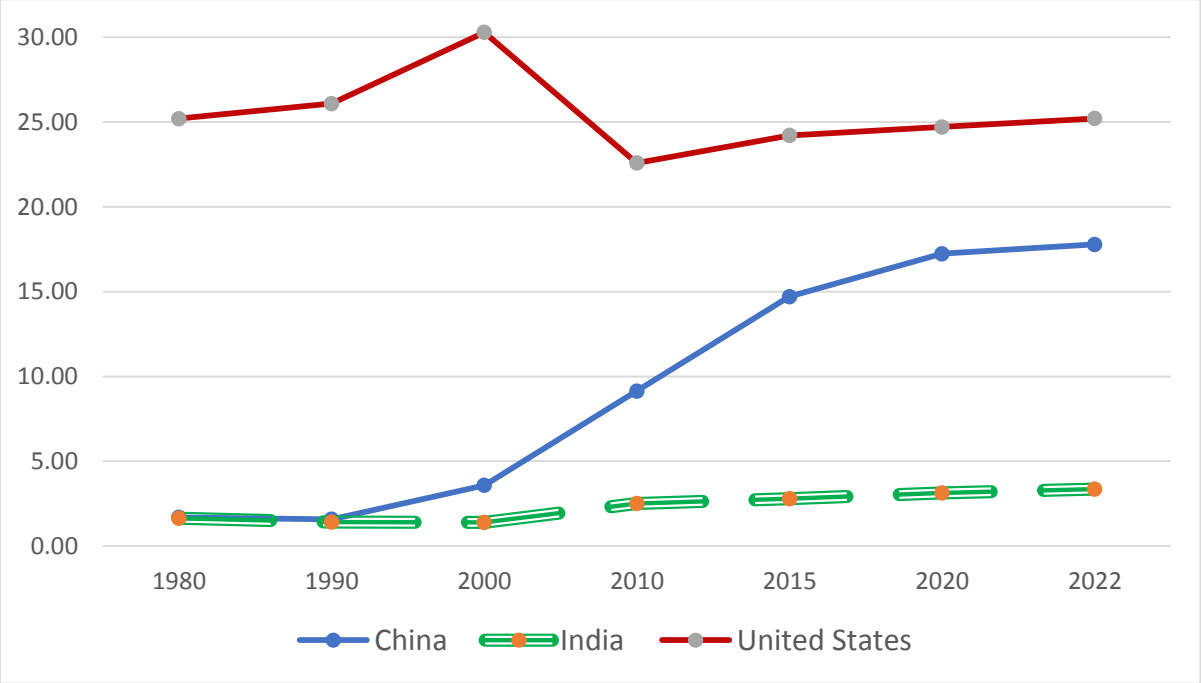

Figure 1. Dynamic graph of the share of the countries' economies in global GDP (in current prices) in 1980–2022, %

Based on data (World Bank Group, 2024)

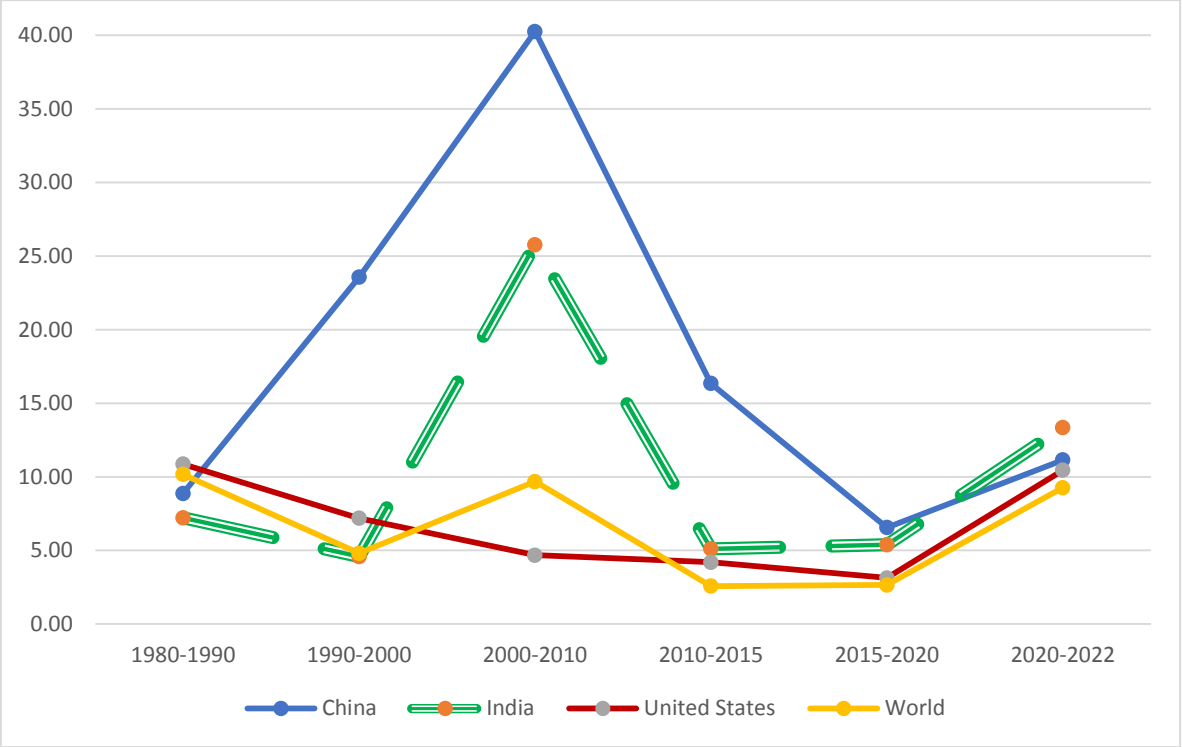

Figure 2. Dynamic graph of average annual rate of GDP growth (in the current prices) across separate countries in 1980–2022, %

Based on data (World Bank Group, 2024)

One of the factors and the consequence of the indicated growth of the country's economy over the specified period as a whole is the increase in the population of the country from 1.15 billion people in 2005, up to 1.42 billion people in 2022 (an average increase of more than 1 % annually) (The World Bank Group, 2024).

Thus, India is gradually becoming one of the world leaders in economic development. The transport industry plays a significant role in the growth of the national economy (Borisov, 2021).

At the same time, the results of the analysis in terms of the functioning of the country's transport system showed that:

- India's economy is extremely energy-dependent (up to 75 % of the consumed oil is imported);

- in the last 20 years alone, the number of vehicles per 100 km of national roads has increased by 3 times;

- it is expected that by 2050 the total number of cars in the country will increase by another 2 times with the projected population growth for this period by 15 %;

- the rapid development of road transport in general over the past 30 years outpaces the similar rates of development of railway transport and related transportation (Borisov, 2021).

In addition, the growth in the population and the number of vehicles is a negative factor in the increase in the number of deaths as result of road accidents (about 150 thousand people annually, or an average of 1 person for 10 thousand inhabitants; even despite the pandemic years and a decrease in the level of transport activity (mobility), the number increased from 150 to 154 thousand people from 2016 to 2021), which is an extremely serious problem for India's transport system and the economy as a whole (Government of India, 2022).

In this regard, ... "the dominance of road transport in the fourth economy of the world with a huge population gave rise to the threat of transport collapse and problems associated with the ecology and alienation of land for new road construction" (Borisov, 2021).

On uST technology (advantages) and possible use thereof in the transport industry of India.

The development of the transport industry in India should comply with modern global trends and requirements for transport technologies: automation, electrification, security in all its aspects, including environmental, as well as economic, resource efficiency, etc. To a large extent, the solution to the above-mentioned transport problems of India can be the use of innovative uST transport and infrastructure complexes, the logic of which functioning harmoniously fits into the world trends in transport development.

In general, uST is an integrated infrastructure solution based on engineering developments and know-how of Belarusian scientist, inventor engineer A.E. Unitsky, which is based on the use of patented string rail technologies and prestressed string-rail transport overpasses, along which mounted or suspended electric unmanned automobiles (unimobiles) on steel wheels move in automated control mode. In general, the composition of the uST complex is shown in Figure 3 using the example of suspended unimobiles.

Figure 3. Schematic representation of the composition of the uST complex

(anchor support, intermediate support, unimobile, anchor support combined with passenger station)

Based on data (Unitsky String Technologies Inc., 2024)

uST transport and infrastructure complexes have a wide scope of application and can be used to solve various transport problems (including in India) thanks to:

- unique design features;

- economic and environmental efficiency;

- possibilities of integration into existing transport infrastructure facilities (airports, railway stations), connecting their elements to each other (terminals, landing platforms);

- creation of new cargo-passenger route networks (routes, systems as a whole) in the region, including in hard-to-reach areas, etc. (Unitsky, 2019).

Currently, the development company (Unitsky String Technologies, Inc., Minsk, Belarus) has implemented a number of commercial projects in Belarus and the UAE, including 2 technology test centers in these countries, where experimental testing of complexes of various types in various natural and climatic conditions is carried out on an ongoing basis. Also, a number of countries (regions) are currently implementing commercial projects related to the design and construction of uST transport and infrastructure solutions.

One of the significant advantages of using these innovative transport solutions compared to traditional ones for the industry is low capital costs for the construction of such complexes. In particular, they depend on the specific parameters specified in the project: performance (speed of movement, interval of movement); design features of the complex (length of spans, number and height of supports); location features (terrain, presence of mountains, water obstacles, etc.); natural and climatic conditions; the level of development of the region and transport accessibility there within; availability of resources and manpower in the market, etc. In general, based on the practice of construction of uST transport and infrastructure solutions by the developer, the amount of capital expenditures per 1 km of the facility is from 7 to 15 million dollars per 1 km.

Table 1 shows the comparison of the average minimum cost of construction of 1 km of transport and infrastructure tracks (solutions), all other conditions assumed equal.

Table 1 – Comparison of the minimum cost of construction of 1 km of transport and infrastructure solutions

Type of transport (solution)	**Bridge (automobile), 4–6 lanes**	**Subway**	**Monorail transport**	**Lightweight rail transport**	**Cable way**	**Suspended string transport by uST**
Photo						
Minimum Construction Cost 1 km, million US dollars	From 100	From 100	From 50	From 50	From 10	From 7

Based on data (Flesser & Friedrich, 2022; Clark, 2021)

The scientific works of the scientist, inventor and general designer of Unitsky String Technologies, Inc., A.E. Unitsky, provide a comprehensive justification of the advantages (including a lower capital cost) of using string transport technology over traditional solutions.

In addition to capital expenditures for construction, the efficiency of uST complexes as compared to traditional solutions is characterized by:

- low power consumption (2–3 times lower compared to traditional modes of transport using steel wheels or a magnetic cushion, and 5–7 times lower compared to road transport);
- reduced cost of transportation;
- minimum land allocation for construction (0.05–0.1 ha/1 km of the route, which requires 30–50 times less land than for the construction of railways or highways of similar capacity);
- long warranty period of operation until overhaul (overpasses – from 50 years, rolling stock – from 25);
- efficiency and low cost of resources for integration into the existing urban and information-communication infrastructure ((Unitsky, 2019; Unitsky, 2016; Unitsky String Technologies Inc., 2024)).

More innovative than traditional solutions in the transport industry (in relation to passenger transportation), which have until now gained a wide practical application (automated passenger transportation systems, or Automated People Mover (APM), Light Rail/ Tram Cars/ Tram-Trains, etc.), have a number of major drawbacks, including those affecting the high cost of construction. Among them – the need to build massive reinforced concrete overpasses, expensive units of rolling stock, allocation of lanes on the ground, etc.

This study presents 4 conceptual examples of possible integration of uST suspension type solutions (in terms of passenger transportation) into the current transport infrastructure of India.

Example 1. Establishment of transport link between two operating terminals located 3.5 km apart on the basis of Chhatrapati Shivaji International Airport (Mumbai).

Analysis of the ranking of the world's largest since 2015 airports by the criterion of passenger traffic, allows India, along with the United States, China and other leading countries, to be among the countries with largest airports. In particular, Chhatrapati Shivaji Airport (Mumbai) is one of the two largest airports in India (along with Indira Gandhi International Airport, Delhi) and is one of the top 30 largest airports in the world.

Currently, transport links between two airport terminals, one of which serves only domestic flights, the second – both domestic and international, are carried out by free buses/shuttles (the average trip duration is 15 minutes). At the same time, one of the main problems for the airport in question is ensuring a quick transfer of transit passengers and moving luggage between airport terminals. Time-consuming movement of passengers and luggage between these terminals due to the lack of effective transport links leads to delays in departing flights, reduction in slots for arriving flights, the number of runways, which does not allow the airport to operate with maximum efficiency.

The transport connection between the airport terminals under consideration can be improved by building uST string rail overpass with the construction of passenger stations and the possibility of their integration into the buildings of existing terminals.

Hereby, the performed calculations, as well as the indicators of trial operation of the implemented uST projects, make it possible to conclude that only one unit of the vehicle (an 8-seater suspended unimobile) can provide passenger traffic in the amount of 1,500 people per day moving between two terminals. The number of units of rolling stock can be optimized based on the congestion of the terminal during peak hours, the average number of passengers per trip, passenger traffic, etc. he estimated travel time from the initial to the final station, due to the design features of the complex and technical characteristics, will be about 3 minutes, whereby in general it will not change at the busiest intervals. Thus, the specified travel time between terminals is 5 times lower than the current one (about 15 minutes), which will also create a significant cumulative effect for passengers in the form of time savings (a cost approach was used to estimate the saved passenger time based on the average salary in India) of about 4 thousand US dollars per day, or more than 1 million US dollars per year, as well as improve comfort and create a "wow effect" based on the introduction of innovative technology.

The following data were used to calculate the specified value:

- *passenger traffic of the airport for the year – about 20 million people, or about 55 thousand people per day;*
- *predicted average daily passenger traffic (movement between two operating terminals of the airport) using suspended unimobiles – the estimated value of 10 % of the daily passenger traffic of the airport, or 5.5 thousand people;*
- *the average salary in India is 7,000 US dollars per year (The World Bank Group, 2024).*

In this regard, we can consider the potential impact of organizing the movement of the uST unmanned electric vehicles around the airport at a preferential or free tariff for passengers (just as it is currently being carried out). The customer's costs for the construction and maintenance of the complex will be compensated by the resulting socio-economic effect described above, as well as the "wow effect" and an increase in image for the region (country) at the world level from the introduction of the uST breakthrough technology. Thus, the implementation of such a project can be of strategic importance not only for the functioning of the airport itself, optimization of passenger traffic, etc., but also for the economy of the entire region (India as a whole).

Visualization of the presented route is shown in Figure 4.

Figure 4. Visualization of uST transport line between two operating terminals (Chhatrapati Shivaji International Airport (Mumbai)

Source: authors' elaboration

Example 2. The uST complex as the connecting transport link between airports and the existing transport infrastructure of urban agglomerations (via connecting Sheikh-Ul-Alam International Airport in Srinagar with the Srinagar railway station).

According to information from Internet-pages of Srinagar Airport, this object occupies a leading position among airports in the country in the category of 2–5 million passengers per year as per the passenger satisfaction, which is determined based on various indicators (transport links to/from the airport, registration, security level, availability of commercial infrastructure). In this regard, special attention is paid to the enhancement of various aspects of the airport's activities by the management and authorities of the region.

At the same time, currently, transport links between the airport and the city of Srinagar are represented by buses and shuttles, which are the most accessible means of transportation for passengers, whereas they have certain disadvantages: frequent shortage of tickets due to the congestion of the route, overcrowding of buses, lack of additional space for luggage, long travel due to frequent traffic jams during rush hours, etc.

Based on the current road transport situation, it can be assumed that creation of the uST complex, which allows moving traffic to the second level, will permit to increase the comfort and quality of provided transport services, but also improve the transport and logistics chain of the region, without increasing the number of ground vehicles, while significantly reducing the traveling time spent by the passengers between flights.

In particular, the airport and the railway station can be connected by a single-line or double-line (if it is necessary to ensure higher performance of the complex) track structure with the possibility of integrating passenger stations into existing transport infrastructure buildings.

In the framework of the considered option, the technical features of the uST complex will allow to overcome the distance between objects in 9 km in less than 7 minutes.

For comparison, the following is currently required for this purpose:

- at least 20 minutes when traveling by taxi;
- considering the interval of movement and waiting time at stopping points – up to 60 minutes.

Depending on passenger traffic and route congestion, the movement of unimobiles can be carried out once every 1–2 minutes or less, which is a significant competitive advantage over existing methods of movement.

The uST complex is highly productive (only 5 unimobiles on this route, with the proper level of optimization, are able to carry more than 7,000 passengers per day, which is comparable to the average passenger traffic of the airport as a whole (about 8 thousand people per day). If it is necessary to increase the capacity of the transport network, the traffic interval can be reduced, which will increase the productivity of the complex as a whole without additional capital investments.

Based on the information provided, analogous to the calculations using the example of Chhatrapati Shivaji Airport (Mumbai), the cumulative effect in the form of time savings for the year can reach 3 million US dollars.

Due to the optimal value of transportation costs, which form the basis of operating costs within the framework of this project, it is possible to organize travel along the route "Sheikh-Ul-Alam International Airport of Srinagar – Srinagar Railway Station" on uST unimobiles at a reduced ticket price in comparison with existing transport methods from the airport to the station, while maintaining the economic attractiveness of this project for the investor.

The visualization option of the presented route is shown in Figure 5.

Figure 5. Visualization of uST transport line between Sheikh-Ul-Alam Airport of Srinagar City and Srinagar Railway Station

Source: authors' elaboration

Example 3. Use of uST suspended complexes as alternative to ground types of intracity public transport (subway, tram, monorail) illustrated by the example of the integration into the existing public transport system of the city of Warangal.

The rapid development and urbanization of the region, the growing population and the number of vehicles lead to the problems of traffic congestion in urban areas, the growth of road accidents and air pollution and give rise to the need to create new generation transport solutions.

Warangal is included in the 100 cities as "Smart City", which gives it the right to receive additional investments for the development of urban infrastructure for a comfortable, environmentally friendly and safe living of the population within the framework of the "Smart City" mission. Hereby, in order to solve transport problems and traffic congestion, the state government is implementing the Metro Neo project – a bus rapid transit system, where only part of the route will run at the second level above the ground. The cost of the project is approximately 135 million US dollars.

As an alternative, it is proposed to consider the uST solution (route, distance exactly corresponds to the Metro Neo project) to create a 15 km overpass-type route network connecting the railway stations of the cities of Warangal and Kazipet with the city of Hanamkonda (visualization is shown in Figure 6) with the ability to provide a capacity of up to 15,000 passengers per hour in one direction.

Corresponding to all the parameters of the Smart City concept, the uST solution is more economical (with the cost of uST complexes from $5 million for 1 km, financial savings compared to the Metro Neo project will amount to 60 million US dollars), more rational and environmentally friendly in terms of land use and safety, since the entire route runs at the second level (above the ground).

Figure 6. Design visualization option of Warangal-Hanamkonda-Kazipet suspension type uST route network with length of 15 km

Source: authors' elaboration

As a result, the uST transport and infrastructure approach:

- will not only solve the problem of traffic jams, but also provide a modern and effective public transport system in the analyzed region;
- can be integrated into the existing passenger route network, thereby expanding and improving the transport system operating in the region.

Example 4. Developing uST transport solutions for India's tourism industry.

The tourism industry in India is one of the fastest growing in the world (The World Bank Group, 2024; Jayasinghe & Selvanathan, 2021). At the same time, many tourist places (regions) in the country remain underdeveloped and difficult to access: remoteness from the main highways and the lack of developed infrastructure are the main obstacles to the development of tourism. In this regard, the country receives insufficient amount of tourists, lowered revenue (profit), tax revenues to the budget, etc.

At the same time, thanks to a number of the structural advantages described above, uST can be used as a means of ensuring transport accessibility of hotel complexes, townhouses, guest houses, etc., located at a distance from the main highways, as well as located on the island or in a hard-to-reach place, via organizing uninterrupted transport links without damaging the landscape.

On the basis of uST technical approach, it is possible to create tourist routes along a coast, which can be connected to existing transport facilities and large highways. The main goal in this case is to increase the transport accessibility for arriving tourists, a straight through delivery to places of accommodation (hotels, settlements), as well as the organization of sightseeing excursions as part of travel around the country.

As example of the implementation of the uST transport and infrastructure complex in the tourism sector of India can be a route in the state of Goa.

Tourists arriving at Manohar Airport, which was opened for service at the end of 2022, and at the railway station will have the opportunity to quickly and comfortably (travel time up to 15 minutes) get to hotels, as well as other places of recreation located on the coast (including currently not developed in terms of transport component), without using additional modes of transport. The distance from the airport to such tourist facilities averages 15 to 25 km. Estimated passenger traffic on the region's most popular routes (tourist resorts on Goa) is up to 1,000 passes per day. Visualization of the offered solutions is shown in Figure 7.

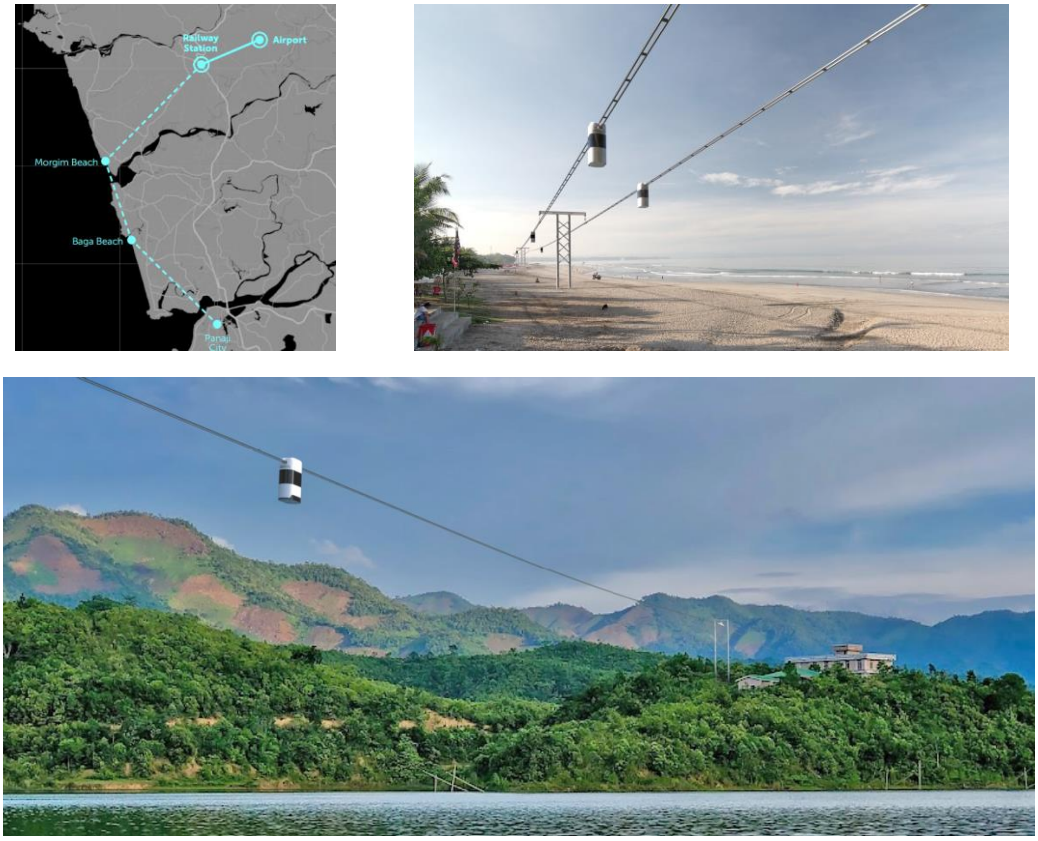

Figure 7. Visualization Options for uST Transport and Infrastructure Solutions for India's Tourism Industry (illustrated by Goa State)

Source: authors' elaboration

As a result, the proposed solutions to the transport problems of the resort regions of India (using the example of Goa) will serve to promote the country's tourism potential and develop unique, but insufficiently popular territories.

Thus, the 4 conceptual examples of the possible integration of uST solutions into the current transport infrastructure of India (in relation to passenger transportation) represent only a small part of the opportunities and prospects from the proposed tool for the scale of the country and its individual industries.

Substantiation of the socio-economic effect of using uST transport and infrastructure solutions in India's economy.

Considering the presented information, the application of solutions based on the use of string transport technologies in India – the country with a growing and one of the most dynamically developing economies in the world – will entail the socio-economic effect formulated in Table 2.

Table 2 – Socio-economic effect of the implementation of uST transport and infrastructure solutions in India's economy

No., benefit for the economy	Brief rationale
1. Transport infrastructure modernization	The possibility of transport infrastructure modernization with minimization of costs (financial, human) for development and current operation of the transport system
2. Savings associated with minimizing operating costs	Savings compared to traditional transport systems are provided by low power consumption, improved aerodynamic and a number of other technical characteristics. Energy (fuel) savings in one unimobile over 25 years of operation in monetary terms compared to traditional rail/wheeled vehicles can exceed $1 million US dollars.
3. Improvement of the environmental component	Deceleration of the growth rate of environmental pollution due to the transition from use of internal combustion engines to electric drives, the abandonment of use of earth-embankments, asphalt and pneumatic tires (in favor of steel wheels moving on rails), as well as organization of movement of vehicles at the "second level" (above the ground surface) with the preservation of the natural landscape, biogeocenosis and biodiversity of the surrounding territory
4. Increase in the level of population mobility	Achieved thanks to the high productivity of the complex (up to 50 thousand people/hour with adaptation to passenger traffic during peak hours), transportation speed (higher than traditional modes of transport), introduction of new routes into operation
5. Increase in investment and tourism attractiveness of the	Will be achieved by introducing breakthrough "green" technologies, developing transport infrastructure and improving transport accessibility (creating new commercial, social and public

No., benefit for the economy	Brief rationale
country and its regions	facilities), including via creation of new routes across hard-to-reach and new territories
6. Driver of further economic growth	Increasing the inflow of foreign investment and the number of tourists, creating new opportunities for development of business and economy on the whole, including in various sectors (manufacturing and mining, metallurgy, electronics, communications, etc.)
7. Improving the quality of life	Will be achieved through the ability to move passengers and goods quickly and safely; at the same time, the population will have access to the necessary additional services and infrastructure facilities (including those built "from scratch")
8. Improvement of the existing road transport situation	Reducing congestion on the road, especially during peak hours; minimizing (reducing to almost zero) the level of accidents and deaths due to elevation of the uST string rail track structure above the ground, functioning of automated control system and presence of anti-derailment system
9. Creation of new jobs	Will be provided as part of the construction of each individual commercial uST (on average at least 20 persons for the operation of the project/route with the corresponding infrastructure)

Source: authors' elaboration

Conclusion

The results of the study showed that at the current stage of the development of India's economy (population growth and GDP; increasing the level of transport activity, environmental pollution, damage to the economy caused by transport, etc.), the innovative technologies and uST solutions are vital and relevant and can be recommended for implementation in the current transport system/infrastructure (illustrated by the example of passenger transportation and specific examples given) with significant socio-economic effect in various directions. At the same time, for India as a country with a rapidly growing economy and the largest population on the planet, the use of the proposed uST technologies can serve as a driver for further development.

In the framework of continued scientific research on this topic, the following measures are considered crucially relevant and planned to be realized:

- elaboration of scientifically based proposals/recommendations on the application of uST solutions based on the example of high-speed and freight transportation (haulage) in the country and its regions;
- development of criteria for investors and a corresponding methodological approach to assessing the choice of the transport system type (mounted, suspended, urban high-speed, intercity high-speed, freight, etc.), which is most expedient for construction in a particular region under existing conditions (geographical, sociocultural, financial and legal, geopolitical and others).

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