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Island Megalopolises: Tunnel Systems as a Critical Alternative in Solving Transport Problems

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ABSTRACT

A principal difficulty with island megalopolises is the transport problem, which results from limited surface land on an already developed island, on which roads and car parking can be placed. This limitation leads to traffic jams on the small number of roads and to intrusive car parking in any available surface location, resulting in safety issues. The city of Vladivostok is located on the Muravyov-Amursky Peninsula in the Russia Far East region (the Primorsky Krai). This city is essentially the third capital of Russia because of its important geopolitical location. To address the car traffic problems in Vladivostok, and because of the absence of places to build new roads, the city administration has proposed the usage of the beaches and waterfronts along the sea coast in this regard. This decision is in sharp conflict with Vladivostok's ecological and social aspirations to be recognized as a world-class city. It also neglects the lessons that have been learned in many other waterfront cities around the world, as such cities have first built aboveground waterfront highways and later decided to remove them at great expense, in order to allow their citizens to properly enjoy the environmental and historical assets of their waterfronts. A key alternative would be to create an independent tunneled transport system along with added underground parking so that the transport problems can be addressed in a manner that enhances the ecology and livability of the city. A comparison of the two alternatives for solving the transport problem, that is, underground versus aboveground, shows the significant advantages of the independent tunnel system. Complex efficiency criteria have been developed in order to quantify the estimation of the alternative variants of the Vladivostok transport system. It was determined that the underground project is almost 1.8 times more advantageous than the aboveground alternative.

1. Introduction

In terms of the number of cars per 1000 inhabitants, the city of Vladivostok strongly holds the first place in Russia, with numbers at 520–560 cars, according to different estimations [1]. The restricted carrying capacity of existing highways demands the development of a new road network. Another problem is the lack of parking spaces for motor transport, which results in spontaneous parking on existing highways, and which aggravates the transport problem even more.

During recent years, much has been made of the traffic improvements that took place in connection with the preparation for hosting the Asia-Pacific Economic Cooperation (APEC) summit; at that time, the basic route from the city center to Vladivostok International Airport was reconstructed and two giant cable-stayed bridges were built. These constructions reduced the stream of cars on the central street, Svetlanskaya Street, and reduced traffic congestion around Lugovaya Square—the most problematic sections of the highway network of the city. However, the improvements that were carried out only partially eased the existing problems.

The transport specificity of the city—that is, its narrow roads, which are not capable of providing the necessary carrying capacity—becomes more complicated by its mountainous relief and its position as an urban territory bounded by an area of surrounding gulfs. In conditions of such dense urban building surface use, the construction of new roads often appears to be impossible. Projects are beginning to appear that make use of the water area of the gulfs; this sharply reduces the infrastructural attractiveness of the territory, depriving the townspeople of places of recreation. All these listed factors demand the creation of new transport

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highways underground by building a system of road tunnels with connected underground parking lots (Fig. 1).

2. Criteria of transport system efficiency

In order to assess the feasibility of accepted designs regarding the disposal of installations that are a part of the urban infrastructure, it is necessary to not only take into account the costs involved, but also the efficiency of the solution with regards to the other priorities of a megacity, such as ecological issues, health and safety, living comforts, and infrastructural attractiveness [2,3].

To estimate the ecological efficiency of tunnel building, it is necessary to analyze the quantity of emissions of harmful substances into the air from motor transport on the city roads in Vladivostok, and to analyze the noise levels of motor transport on city roads.

2.1. Criterion of ecological safety

It is obligatory for the state structures of management and the consideration of economic activities that the state standards regarding the safety of products, works, and services reflect an encompassing view of the life and health of a region [4,5]. We observe the state of the environment in Vladivostok from this position.

2.1.1. Estimation of quantity of harmful atmospheric emissions

Motor transport is the main source of the harmful emissions that are polluting the city's atmosphere. The meteorological agency reports that in the case of Vladivostok, the specific parameters of the dispersion of harmful emissions from motor transport are an additional factor toward the city's environmental decline [6]. This problem is now at an acute level in the main parts of the city.

Emissions from motor transport were 2.015×10^5 t in 2011 (i.e., 47.25% of the total volume of emissions in the region) [7]. The concentration of exhaust fumes at traffic signals and in residential areas is especially high. At peak times at locations such as crossroads, traffic jams form, cars consume oxygen, and the aerosphere is saturated with exhaust fumes. In the city of Vladivostok, rush hours occur in the morning, when adults leave for work and take their children to school or daycare, and in the evening, when they return home.

Fig. 1. The radial-ring circuit project for a road tunnel system in the city of Vladivostok. (1) Tunnels; (2) underground parking lots.

The monitoring of air pollution, as recorded by the city administration of Vladivostok in 2010, is presented in Table 1 [8]. There is a mid-year concentration of nitrogen dioxide and dust that exceeds the maximum concentration limit by 1.5–2 times.

According to the relevant research, the air basin of the city of Vladivostok is dangerously polluted by nitrogen dioxide, which irritates and frequently attacks the mucous membranes of eyes and lungs. This gas can cause a considerable deterioration in existing diseases of the respiratory system, such as bronchitis and asthma, and can cause infections of respiratory airways to be more easily and quickly spread. Nitrogen dioxide can be seen as a serious health hazard to the population [9]. This situation was dramatically worsened after the road construction for the APEC summit (Table 2).

A feature of harmful emissions underground that distinguishes them from emissions on the surface is that they can be "regulated." That is, the volatile exhaust gases from cars on the surface are widely distributed, making "catching" them impossible. Regarding gases in a tunnel, their distribution is limited by the tunnel walls, so they can feasibly be captured because forced air circulation is necessary for normal functioning of the underground structure. On being delivered to the surface, return air will pass through a ventilating fan and can also be directed through air scrubbers, thereby allowing the air to be cleaned and the harmful gases to be neutralized. The quantity of harmful emissions thus decreases.

Another advantage of the road tunnel system is that its use will lead to a sharp decrease in the time spent in a motor vehicle, resulting in a reduction in traffic congestion and increased fuel economy. By a tentative estimation, the quantity of harmful emissions in the atmosphere after the building of a network of road tunnels will be reduced by 8–10 times.

If the degree to which the maximum air pollution concentration levels were met was to be measured both before and after the building of a road tunnel system, a 10-point scale can be applied to understand the tunnel system effectiveness. In this case, 10

Table 1
The general emission of contaminants by vehicular traffic in residential areas of the Primorsky Region in 2010.

Types of transport facilities	Fuel types	Quantity of vehicles	Contaminants (tons)
Cars	Gasoline	479 888	61 562
Trucks and buses with a full weight less than 3500 kg	Gasoline	38 133	31 413
	Diesel	10 895	1 381
Trucks greater than 3500 kg	Gasoline	25 273	54 653
	Diesel	56 864	18 477
Buses with a full weight greater than 3500 kg	Gasoline	1 484	7 723
	Diesel	2 444	1 576
Total		614 981	176 785

1 ton = 907.18474 kg.

Table 2
The general emission of contaminants by vehicular traffic in residential areas of Primorsky Region in 2013.

Types of transport facilities	Fuel types	Quantity of vehicles	Contaminants (tons)
Cars	Gasoline	736 811	94 522
Trucks and buses in full weight less than 3500 kg	Gasoline	29 147	24 011
	Diesel fuel	8 097	1 027
Trucks greater than 3500 kg	Gasoline	17 618	38 100
	Diesel fuel	39 641	12 880
Buses in full weight greater than 3500 kg	Gasoline	1 982	10 316
	Diesel fuel	3 264	2 106
Total		836 560	182 962

points means that the levels were completely met and one point means they were not met at all. Therefore, in the case of this project, the "before building" score would be one point and the "after building" score would be seven points.

2.1.2. Estimation of noise level of motor transport

"Noise" denotes any unpleasant and undesirable sound or series of sounds that prevents the perception of a legitimate signal, breaks the silence, has a harmful and irritating impact on a human body, or reduces the human body's working capacity [10]. Unlike noise, "sound" is a physiological phenomenon that is defined by the sensation that is perceived by an organ of hearing and by the interaction of acoustic waves with that organ. Therefore, we perceive sound as a physical phenomenon and noise as an ecological parameter. According to the city administration of Vladivostok, the noise level at the locations of basic grade crossing-interchange structures reaches nearly 70 dB(A), which significantly exceeds the norms of 55 dB(A). The maximum levels of noise were observed during hourly intervals at different times of the day: 8:30–9:30; 13:30–14:30; and 16:30–17:30.

The architectural planning structure of Vladivostok does not consider transport noise. Noise abatement in cities should include an appropriate organization of buildings and designing of roads, the use of mufflers in automobiles, and the presence of green plantings. Dealing with street-level noise by making attempts at isolation is only a half measure. It is necessary to deal with the cause rather than just with the consequence. After the construction of a road tunnel network (a ring and radial tunnel system), the bulk of general car traffic would use the underground roads, and the city's noise levels would be lowered accordingly.

By a tentative estimation, the noise level at the locations of basic grade crossing-interchange structures after the construction of a road tunnel network would be 50 dB(A). If the degree to which the maximum desirable noise levels were met was to be measured both before and after the building of a road tunnel system, based on the same 10-point scale as above (where 10 points means that the levels were completely met and one point means that they were not met at all), then the "before building" score would be one point and the "after building" score would be seven points.

It is further necessary to consider that noise abatement not only creates comfortable conditions for work and life, but also provides notable indirect economic benefits, since noise is useless dissipated energy that serves to decrease the working capacity of people.

2.2. Safety of traffic

Under Russian legislation, traffic safety is the condition of the given process that reflects the extent of the protection of motor traffic participants from road and transport incidents and their after-effects. Road and transport incidents (i.e., road accidents) are events that originate in the course of traffic on the road, and that involve transport facilities, through the participation of which people perish or are wounded, and whereby transport facilities, constructions, or cargoes are damaged, or damage to other material is caused. Road and transport incidents do not include accidents that only involve pedestrians (i.e., falling in the road, being knocked down by a crowd, etc.) [10].

Traffic safety in tunnels, as a rule, is higher than traffic safety on open sections of road (the number of road accidents in tunnels is approximately 50% less; however, the after-effects of a road accident in a tunnel are more serious). At the same time, tunnels not only allow the essential short-cutting of distances between regions and cities that are separated by mountains, but also provide the delivery to regions and cities of vital cargoes under extreme weather conditions. Such weather conditions are characteristic of Vladivostok: In the summer, there are typhoons, while in the winter, there are intensive snowfalls and blizzards.

To improve tunnel safety, appropriate active measures to prevent crashes and passive measures to decrease the after-effects of crashes should be taken. However, experiences in tunnel construction development, both in Russia and abroad, show an essential increase in traffic safety in tunnels over surface roads. This increased safety has been attained through the use of modern hardware components to control traffic, work the ventilation and pump plants, improve fire safety, monitor the presence of detrimental impurities in the air, control the electrical supply, and control the illumination, along with other functions.

If the level of traffic safety was measured after the introduction of a network ring and radial road tunnel system in the city of Vladivostok, based on the same 10-point scale (where 10 points means that the levels were completely met and one point means that they were not met at all), then the "before building" score would be one point and the "after building" score would be eight points.

2.3. Infrastructural attractiveness of the project

The parameter of infrastructural attractiveness is considered to be especially important in projects that involve making radical changes to the transport system of an entire city or its separate regions. In this case, the times of the main volume of passenger traffic and the time spent in transit by different groups of citizens are subject to estimation. The time that is currently spent in transit within the city boundaries, based on the accepted estimations of more than 20 min, makes traveling difficult [11]. In addition, the stability of the transport system of a city is a vital problem for all megacities, in terms of the parameters of infrastructural attractiveness. In the case of Vladivostok, the most serious problem is the weather conditions during the winter and summer periods, which are defined in the winter by snowstorms and in the summer by typhoons.

An estimation of the infrastructural attractiveness of the design of the construction of a network ring and radial road tunnel system in the city of Vladivostok provides a "before building" score of one point and an "after building" score of 10 points.

2.4. The technical and economic analysis of the project

The technical and economic analysis is based on decision-making about building and on examining the alternatives. The general effective solution to the city's transport problem is presented in Fig. 1, which shows the proposed underground radial-orbital road tunnel system along with a series of underground parking facilities in the central sections of the city.

A comparison of the construction alternatives at cost shows that all of these lie over the range of 60–120 billion RUB ($1–2 billion USD). This is comparable with analogous projects in Norway (i.e., Hordaland) and Switzerland (i.e., Zurich), which were accepted for analogue purposes. Construction times also vary depending on the accepted engineering technology. However, using a shield method of construction, the project would take 8–10 years to complete. These estimations suggest that the proposed solution to Vladivostok's transport problems is both technically and economically realizable.

3. The complex estimation of efficiency of building

The complex task of estimating the efficiency of the tunnel construction was performed by comparing a set of key parameters regarding maintaining the roads now with the equivalent parameters regarding maintaining them after the tunnels network has been built, and by expressing the economic, social, and ecological effects in the form of points. In addition, the multi-parameter optimization design process assumes a comparison between the various proposed designs; here, it is not enough to make a technical–economic analysis.

Analyzing the traffic situation "before and after building," it is clear that the efficiency of the "ecology" section will be judged on two factors: air and noise pollution levels. The "after building" score is seven points whereas the "before building" score is one point at the locations of basic grade crossing-interchange structures. This increase in efficiency is attained as the result of a substantial cut in the time spent in a car when using the tunnel system. That is, instead of a car spending 1 h standing in traffic congestion on the surface road, it will spend 5 min driving in a tunnel.

The "safety" section scores eight points for "after building" against one point for "before building"; the "infrastructural attractiveness of the project" section scores 10 points "after" against one point "before." Summarizing these sections, the "after building" score is 25 points whereas the "before building" score is three points.

The complex criterion of the estimation of the efficiency of the underground construction, K_{CE}, can be accepted in the following equation:

$$K_{CE} = \sum_{i=1}^{N} q_i K_i / N \tag{1}$$

where K_i represents the estimations on separate aspects of i parameters, q_i is the relative "weight" of the ith parameter, and N is the number of parameters.

For the conditions of Vladivostok and the equal "weight" of the considered parameters, the value $K_{CE} = 8.3$ is attained. This is a very high parameter, testifying to the efficiency of the proposed project.

Compared with the surface transport system project (Fig. 2), the underground tunnel system provides much more important advantages, which are outlined in Tables 3 and 4. The quantity estimation shown in Table 4 shows that the tunnel system is 1.8 times more advantageous, on average, than the surface transport system project.

The incorporation of an underground ring-road design into Vladivostok's transport system, as compared with land traffic, scores in terms of the speed of traffic flow, the time spent in transit, ecological compatibility, and safety; thus, this project will increase the infrastructural attractiveness of the capital of the Russian Far East region in terms of both business and residences.

Table 3
Comparison of the VCR project with the tunneling project (quality).

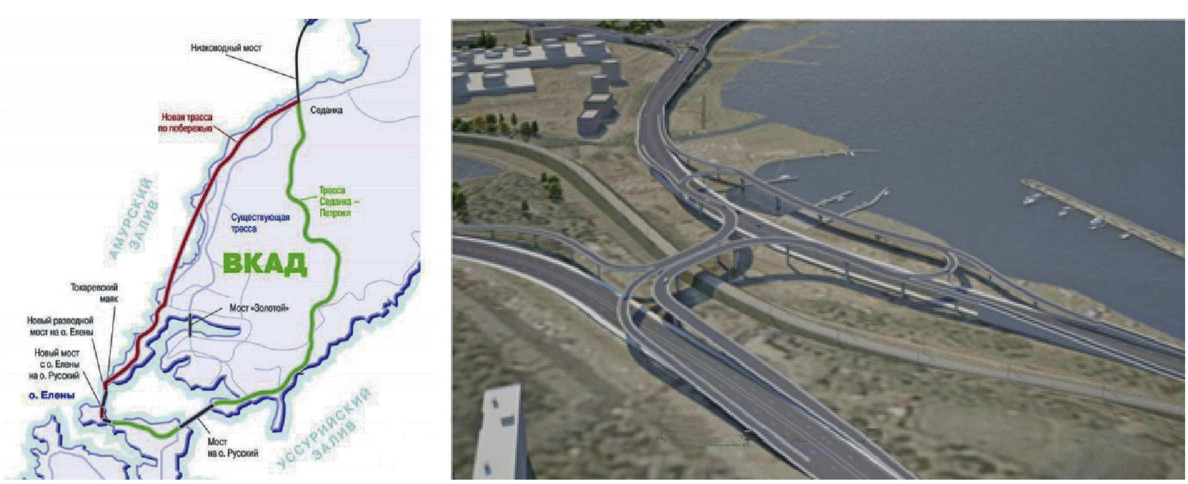
Factor	VCR	Tunneling	Comparison
Cost (billion RUB)	55	60	Comparable
Time construction (years)	5	8	Comparable
Traffic jams	Incomplete decision	Complete decision	Tunneling +
Ecology: air quality	Incomplete decision	Complete decision	Tunneling +
Ecology: noise	Incomplete decision	Complete decision	Tunneling +
Car parking	No	Full decision	Tunneling +
City infrastructural attractiveness	Sharp fall	Sharp rise	Tunneling +
Project investment attractiveness	Average	High	Tunneling +

Table 4
Comparison of the VCR project with the tunneling project (based on the 10-point scale).

Factor	VCR	Tunneling	Comparison
Cost	6	5	Comparable
Time construction	7	5	Comparable
Traffic jams	5	8	Tunneling +
Ecology: air quality	5	9	Tunneling +
Ecology: noise	6	9	Tunneling +
Car parking	0	10	Tunneling +
City infrastructural attractiveness	1	9	Tunneling +
Project investment attractiveness	5	9	Tunneling +
Average	4.4	8.3	

4. Other potential development impacts of the project

Studies of the development of underground space in cities use parameters such as the relationship of the area of the underground part of the construction expressed as a percentage to its total area. In urban conditions, this can vary from 4% to 87.5% [12]. By increasing the use of underground space, the comfort of living conditions for the city's population can also be increased. To take full advantage of the road tunnel project, it is necessary to investigate the feasibility of building ancillary underground constructions—perhaps using open-cut construction methods. "If so, up to 70% of the total amount of parking and garages, 80% of warehouses, 50% of archives and storage, and up to 30% of factories could be built below the surface" [13].



(a) (b)

Fig. 2. The Vladivostok circular roadway (VCR) project. (a) Principal scheme; (b) 3D project.

The network of an orbital and radial-road tunnel system could become the basis for the development of a distributed industrial and service-oriented underground complex. However, in order to realize further plans for such below-the-surface development, additional in-depth social, economic, and ecological estimations are required regarding the creation of such new urban territories, industrial zones, and service zones, and regarding the resulting impact on the mountainous, geological, and megacity environmental conditions.

5. Conclusion

Vladivostok is a city with an acute shortage of building space; to overcome this issue, it is necessary to create and use underground space, as has been done in countries including Norway, Japan, and China. Experts consider the creation of an underground transport complex in Vladivostok to be feasible. In the landform of a city such as Vladivostok, with its surrounding mountainous terrain, transport is very difficult. However, tunnels can be built through the hills, and can incorporate the parking and other infrastructures necessary for a city.

The construction of a road tunnel network in the city of Vladivostok will significantly solve a number of problems by:

- Making rational use of land territory;
- Organizing the population's transport services and improving traffic safety;
- Decreasing the street noise and air pollution caused by car exhaust fumes; and
- Increasing the infrastructural attractiveness of the city.

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