Technical and economic analysis of Unitsky String Transport and its comparison with urban the existing public transportation

Profitability of an urban route of Unitsky String Transport (UST) and its recoupment depends on a number of factors such as the cost of the road, infrastructure and the rolling stock, the volume of transportation, operation costs and the cost of tickets.

The cost of a principally new transportation system is not regarded as a determining factor in the course of the decision-making for its construction. It was always so, in all historic times, that a new system and its components were more expensive than existing transportation systems. For example, the cost of a railway road and its rolling stock is higher than that of cartage transportation and its rolling stock: horses, carts, stage-coach. A steamer is more expensive than a sailing vessel; an aircraft is more expensive than a locomotive and an airport is more expensive than a railway terminal. The cost of a highway is higher than that of a dirt road as well as the cost of a car is higher than the cost of a horse and a cart. However, all this was not an obstacle to promote the use of new transportation systems because alongside with the economic factors there are a number of other non-economic factors that determine the situation.

The transportation system itself as well as its cost actually is not very much interested for a user who pays his fare to get the transportation service he needs, therefore, indirectly he pays for the system construction and operation. First of all, users are interested in the quality of the service provided: comfort, safety, all-weather operation, environmental impact and accessibility. The cost of the transportation system in transportation service does not have a predominating role but rather makes a part of its economic component.

It would not be correct to compare technical and economic characteristics of the existing transportation systems with all their components manufactured on a serial basis during many decades and the introduction of a new transportation system with its first tracks to be built according to the individual projects (it refers to all system components: a track structure, supports, infrastructure and the rolling stock). In this case rise in price observed at the first stage of application should not be regarded only in the economic terms as a considerable drawback. On the contrary, it will open up a possibility to create new industries and new jobs that could bring the growing earnings to the income part of the city budgets that would be considerably higher than the actual expenses for their creation[1]. Therefore, it would be more appropriate to consider the issues of UST recoupment and profitability not with regard to the operation of its first section but rather with regard to the subsequent sections when serial production has been launched.

All estimates were made on the basis of current prices in construction: assembled metal structures (made of non-deficient marks of steel used for the production of reinforced elements

[1] It is necessary to note that creation of principally new transportation systems and their components, in particular, the rolling stock, under the current conditions is associated with extremely high costs. For example, the cost of the development of a new A-380 airbus for EU was estimated at 20 billion Euro, development of a train on a magnet suspension in the USSR (that still remains unrealized) – at 5 billion rubles, a train on a magnet suspension ("Transrapid") in Germany – 6.5 billion Euro, a mono-rail in Moscow – USD 100 million, a new mark of a passenger car – USD 1 billion. In case of a UST its investor is not required to invest money to the development of a string transportation system because this work has been already done by the UST developer in the course of more than 25 years of his activity. At the first stages of implementation only additional, relatively small costs, will be necessary to adapt the system to the concrete natural and climatic conditions, to undertake its certification and create jobs at the customer's site with the aim to promote the small-scale serial production of a track structure, supports and transportation modules both for a concrete UST route and for the implementation of additional orders including those coming from the abroad.

and railway rails) – 2,500-3,000 USD/t; assembled reinforced structures (made of concrete of 300-400 marks) – 300-400 USD/cub.m; concrete laid in the structure – 100-150 USD/cub.m.

Material consumption and approximate cost of a double-track UST route of serial production (not including infrastructure and the rolling stock) under the city conditions are given in Table 1 (only constructive part was considered not including additional architectural and planning solutions that could be made on the basis of aesthetic, representative and other considerations; the given data refer to the conditions of a Russian city).

Table 1.

Material	Consumption per 1 km of a route	Cost of the assembled structure, thous. USD/km
1. Steel (traditional, non-deficient marks)	160-200 t	400-600
2. Reinforced concrete	200-250 cub.m	60-100
3. Concrete	100-150 cub.m	10-25
4. Other materials		30-75
TOTAL:		500-800

Including infrastructure and the rolling stock (on the average estimated as 2 transportation modules with the capacity up to 45 passengers per 1 km of a route) the cost of a double-track UST route of a serial production under the city conditions will be 1.1-1.5 million USD per 1 km.

Therefore, UST is an exception, because the cost of a serial route of the second level will be approximately the same as the cost of the existing ground urban transportation systems:

- Trolley-bus line – two lanes (in two directions, each with the width of 3.5 m), road cover, contact network with electric insulators and supporting cables, poles to support the contact network, power cables, transformer substations, urban land occupied by the system – with their total cost at the level of the cost of a constructive part of a UST (500,000-800,000 USD/km). Including infrastructure (stopping areas and pavilions, trolley-park, etc.), the rolling stock and land occupied by the infrastructure the cost of 1 km of a double-track trolley-bus line is estimated at the same 1.1-1.5 million/km as the cost of UST.
- Tram line – rails, sleepers (or plates), rubble or sand cushion, earth works, asphalt-concrete or reinforced concrete road surface to cover the sleeper grid, contact network with electric insulators and supporting cables, poles to support power cables, transformer substations, urban land occupied by the system the cost of which will be at the level (if not higher) of the cost of the constructive part of UST (500,000-800,000 USD/km). Including infrastructure (stopping areas and pavilions, switching devices and turn-table rings, tram depot, etc.), the rolling stock and land occupied by the infrastructure the cost of 1 km of a double-track tram line is estimated at 1.1-1.5 million USD/km, i.e the same as that of UST.

For comparison, the cost of two other transportation systems of the second level that are currently used as urban public transportation is as follows: a mono-rail road – 15-25 million USD/km and more; train on a magnet suspension – 30-40 million USD/km and more; mini-metro – 20-30 million USD/km and more.

In addition to the aforementioned UST alternative (macro-UST with a wide 2-meter gage and a transportation module which analogue in the ground transportation is a bus) the following alternatives have been developed:

1. Mini-UST that will be approximately by 1.5-2 times cheaper than macro-UST (a gage width – 1.5 m; module capacity is similar to that of a micro-bus – 7-15 passengers);

2. Micro-UST the cost of which will be approximately 1.5-2 times lower than that of a mini-UST and 3-4 times lower than that of a macro-UST (the gage width – 1m; module capacity similar to that of a passenger car – 4-6 passengers).

In spite of the reduced dimensions of these transportation alternatives they will be characterized by the sufficiently high carrying capacity under the city conditions, namely: mini-UST - up to 3 million passengers per year; micro-UST – up to 1 million passengers per year.

For the objective comparison of technical-economic and other indices of various urban transportation systems let us consider them in terms of the transportation service provided that is paid directly by the user.

Comfort

- Alongside with the comfortable solution of its main functional task - quick and safe delivery of its passengers – UST opens up a possibility to solve aesthetic functions. Large glass-enclosed area, comfortable seats, soft velvet track turn your trip along an ordinary road into a pleasure of having a bird's eye view of the surrounding urban landscape. Each transportation module is provided with a climate-control system to make clean the initial air that is taken at the height of 5-6 m (rather than at the asphalt surface as in the existing urban transport) and, as opposed to motor roads, to eliminate the smell of combustible and lubricating materials and heated in the sun asphalt and exhausts from motor car flows, etc.

- Movement of rail cars along the string track structure does not depend on weather and road conditions (wind, rain, snow, fog, glaze of ice, etc.), there are no traffic signals and intersections at the same level with other modes of transportation or pedestrians, therefore, the average travel speed of UST will be higher than that of the existing road transportation. It will ensure the higher level of comfort for its passengers who could make use of the transportation service offering them the higher-speed, safer and more comfortable travel conditions.

- High frequency of circulation (every 2-3 minutes or 1-2 minutes during "rush-hours") and a relatively small capacity of the transportation modules make it possible to avoid crowding of passengers at the stops, to speed up loading and unloading of passengers and, ultimately, to raise the general comfort level of the transportation service provided.

- Thanks to the small dimensions of the rolling stock and its reduced capacity (as compared with a bus, trolley-bus or tram) the UST rail cars could ensure a high-frequency of circulation (every 2-3 minutes or 1-2 minutes during "rush-hours"). Therefore, passengers will not need to stay long at the stops waiting for a car which is especially important under the extreme weather conditions (strong frost or wind, shower rain, hot, etc.) or for aged people, children or people with poor health.

- Buses, trolley-buses and trams due to their large-scale dimensions in many cases become the sources of traffic jams in the city streets, creating discomfort not only for their passengers but also for the users of other modes of urban transport including users of individual cars and taxi.

- Electric network of the existing electrified urban transportation is regarded as its weak point because among their very frequent occurrences are the dead lines, breaking of copper wires, destruction of electric insulators, shorting, etc. which disturb the general traffic circulation schedule and create discomfort for passengers.

Safety

- Destruction of a track structure constitutes the greatest hazard to rail transportation. Let us consider a possibility of such destruction in UST. Construction norms and rules (SNiP 2.05.03-84*) "Bridges and Tubes" assume the designed tensions in the high-strength wire of span bridge structures, for example, for the wire with 5 mm diameter, in the amount of 10,750 kgs/sq.cm or maximum (destructive) tension for the same wire is 17,600 kgs/sq.cm. During the whole service life (100 years) of a macro-UST the tension stress in a string of its track structure will vary from 8,635 to 10,750 kgs/sq.cm and in this case the string tension will vary under the impact of various factors in the following range: temperature change (from +45°C to – 55°C) - 2,000 kgs/sq.cm; maximal wind (speed – 250 km/hour) – 30 kgs/sq.cm; maximal glaze of ice (20 kg of ice per 1 linear m of a string-rail) - 25 kgs/sq.cm; rolling stock (two coupled modules moving in the middle of a span) - 60 kgs/sq.cm. In this case the safety factor of a string with regard to the tensions of the rolling stock will be: (17,600 kgs/sq.cm – 10,750 kgs/sq.cm) / 60 kgs/sq.cm = 114 times. None of the existing transportation facilities has a similar (100-fold) safety factor while in UST it is created thanks to a particular, specific only for a string system, kinematics scheme of external loads (cross-sectional in relation to the string). The given example shows that breaking of a string is possible only if instead of the designed 6-ton module a system will use a transportation vehicle which weight exceeds 600 tons or if the wind speed exceeds 1,000 km/hour or the frost is more than -200°C which is unreal.

- A rail UST car is characterized by the high stability of moving along the track structure which could be attributed to the availability of two-rim wheels, independent suspension and high aerodynamic qualities of its body. The operational models at scales 1:15, 1:10 and 1:5 as well as the pilot UST section were used as a basis to model various emergency situations. For example, destruction of two intermediate supports at a time, availability of outside metal objects with the height up to 3 cm on two rails, strong side wind and a 10-magnitude earthquake by Richter scale affecting simultaneously did not result in the derailment of a rail car moving at the low speeds (up to 80 km/hour).

- The UST rolling stock remains operational even under the hurricane wind. For example, in order to throw a rail car down the track the force of the side wind pressure should exceed the weight of a module and for that the wind speed should be more than 600 km/hour which is unreal.

- The number of people killed annually in Russia as a result of road accidents (including highways and railways) amounts to 35,000-40,000 people and this figure is growing every year. In cities the main sources of the growing number of road accidents and human deaths are buses, trolley-buses, trams and mini-buses. During the next 50-100 years (service life of UST) the average number of people killed or injured (to become invalids or cripples) as a result of accidents in the aforementioned roads with the total length of 800,000 km will amount to about 2-4 million and 20-40 million, respectively, i.e. 2-5 person/km or 25-50 person/km, respectively. A rail UST system elevated above the ground to the second level will be characterized by a considerably lower accident rate than the existing high-speed railways laid on the ground surface (for example, during 40 years the high-speed railways in Japan, enclosed and elevated above the ground, carried about 10 billion passengers and none of them was killed). The cost of 2-5 human lives and 25-50 cases of disability per 1 km of existing roads exceeds the cost of 1 km of UST routes. This factor alone could justify construction of rail roads of the second level based on string technologies as being safer and lower-cost than traditional beam structures of span facilities.

- In electrified urban transportation there is a risk for its servicing staff and passengers to be exposed to the impact of high electric tension.

All-weather operation

- UST is all-weather transportation. Therefore, neither shower rains or hurricane winds and snow drifts in the streets could disturb its normal circulation schedule. UST remains operational during the floods when urban road transport is paralyzed, or during earthquakes or other natural disasters. Cutting off current in the city (as a result of natural disasters or failure in the operation of power plants or electric networks) would not have any impact on UST operation either.

- UST track structure does not require special measures in winter to remove snow or ice while maintenance of urban streets and roads in the normal condition during the long winter period is associated with large costs estimated at USD 10,000-20,000 per year per 1 km (including salary for the servicing staff, the cost of snow-removal vehicles and dump trucks, fuel and lubricants, deterioration of road and traffic conditions during the snow-removal period and the growing number of road accidents resulting in the damage of vehicles, injury and death of people, standstill of public and private transportation, delays with commuting as a result of traffic "jams", consumption of anti-freezing reagents, etc.). During the service life of UST (50-100 years) the relevant savings in the city budget could amount to about 2 million USD/km which considerably exceeds construction costs per 1 km of a UST route.

Environmental qualities

- Large-sized, heavy and powerful buses, trolley-buses and trams are the main sources of noise in the cities and in terms of its hazardous impact on human health noise occupies the first place among other factors. In trams the major sources of noise include the rail joints, large mass of undressed steel wheels, wheel truck and tram itself, uneven track laid on a ballast cushion, current collector; in trolley-buses it is a powerful engine with a reducer, tire protector, current collector. In UST the indicated sources of noise are absent.

- Existing urban transport is a source of soil vibration which has a negative impact not only on people but also on urban buildings and facilities. UST does not cause soil vibration thanks to its very smooth track, the lack of joints (a rail is welded in one weaving), damping of wheels, string-rail and reinforced supports, small mass of undressed steel wheels of a module and the mass of a module itself.

- Contact network of a trolley-bus or bus is often sparking and creates radio interference and electric magnet pollution of urban environment.

- Contact network of a tram or trolley-bus hanging above the street with numerous bracing wires stretching to the masts and building walls, electric insulators, masts on pavements worsen the image of urban built-up environment, its aesthetic perception, and represent a visual intrusion and visual ecological hazard.

- Large mass of the rolling stock in existing urban transportation per 1 passenger and high moving resistance (aerodynamic, rolling and current collector resistance) results in the excessive drive power of the rolling stock: 3-4 kWt and more per 1 passenger for a bus, trolley-bus and tram (or 10-15 kWt/pass. at small loads which is a usual occurrence); 5-6 kWt/pass. and more for a mini-bus; 20-50 kWt/pass. and more for a taxi and individual cars. Engine power in UST modules (dry weight is about 3 tons at the capacity of 40-45 passengers) amounts to 1.5-2 kWt/pass. which means that at the same transportation work in terms of its environmental qualities UST will be more efficient than existing urban transportation and passenger cars by 1.5-2 and 10-20 times, respectively.

- UST is the most environmentally clean transport among other known modes of transportation (including trolley-bus and tram) which is attributed to the availability of steel wheels and a steel rail (the rolling resistance of a module wheel is 20-30 times lower than that of a rubber wheel of a trolley-bus), high aerodynamic qualities of the module body (5-6 times better than those of a trolley-bus or tram) and lower material consumption of the rolling stock which consumes energy mostly for acceleration and braking (80-100 kg of dry weight per 1 passenger against 150-300 kg/pass. for tram and trolley-bus). Actually, at the same transportation work pollution of urban air by the products of fuel combustion from UST (with internal combustion engine) or energy consumption (by electrified UST alternative) will be the lowest.

- As possible fuel for a diesel of UST module (for non-electrified alternative) it is envisaged to use synthetic gasoline – dimethyl ether synthesized from methane which production could be initiated in any city (for example, in Moscow it is produced on the basis of a very simple plant). Combustion products of such fuel (water and carbon dioxide) are similar to those of methane and natural gas and they are environmentally clean. Such fuel is 1.5-2 times cheaper than traditional diesel fuel and it is ideal to start the engine at any frost, its resource is 1.5-2 times higher and combustion products are free from carbon black and noxious substances (lead, sulfur, etc.).

Accessibility

- UST route could be built in the built-up environment, squares, parks and other urban areas not suitable for the construction of tram or trolley-bus lines. In some cases UST routes could pass through residential and office buildings, shopping centres and other urban buildings and facilities, i.e. in the immediate vicinity of passenger flow generation points. These possibilities of the second level transportation are currently used to build mono-rail roads in various cities of the world. Therefore, in terms of walking accessibility UST is more preferable than ground modes of urban transportation.

- In terms of the ticket cost UST will be at the level of tariffs for urban public transportation, thus, being affordable for all groups of population including the low-income citizens.

Other economic and non-economic factors

- Construction of a UST route in the city does nor require construction of bridges, overpasses, underground and overhead pedestrian crossings, multi-level exchanges which construction costs at traditional urban roads are usually higher than the cost of roads themselves.

- UST is a second level transportation with its track structure installed on the supports elevated above the ground. It contributes to the reduced land allocation requirements for construction amounting to 15-20 sq. m and 40-50 sq.m per 1 km of a double-track road for intermediate and anchor supports, respectively. For comparison: trolley-bus, bus and tram transportation require 0.7 ha/km (7,000 sq.m/km) of valuable urban land (with its total cost amounting to 0.5 million USD/km and more).

- The cost of 1 sq. m of the carriageway of urban roads designated for the passage of heavy buses and trolley-buses is approximately the same as the cost of 1 sq.m of the floor area in a new residential house (500-800 USD/sq.m and more). However, in terms of its reliability and durability the carriageway of Russian roads is worse than that of foreign roads (in a number of foreign countries the width of the road top dressing reaches 1.5 m and more), therefore, in the course of time the cost of the road bed will be growing both as a result of the increased material consumption and rise in prices for these materials.

- Asphalt-concrete coverage of urban roads is in need of annual repair including fixing of temperature cracks, pot holes, etc., elimination of asphalt swellings and so on as well as every 10-15 years a new layer of asphalt-concrete coverage is needed. In this case the average annual costs are estimated at 5,000-10,000 USD/km which during the 50-100-year operation (service life of UST) will make 0.25-1 million USD/km.

- UST could provide traffic circulation without intersections and traffic lights that are the main sources of excessive fuel consumption by the existing urban transport, air pollution and smog as well as result in the traffic “jams” and noise in the streets.

- UST string-rail could be used to accommodate urban communication lines (wire and fibro optical ones) and its supports – to install radio-relay and cellular communication nodes.

- UST supports could be used to install street lighting devices therefore eliminating the need in lantern masts.

- Each anchor support of UST combined with a stop could be used to locate one- or many-level (including underground) shops, public catering and service facilities (such as repair shops, currency exchange offices, etc.), recreation and entertainment facilities, etc., therefore, anchor supports and stations are capable to pay back their expenses independently.

- Each intermediate support of UST could be used to install two advertising places (one on each side), therefore, these supports could pay back their expenses independently not including a track structure. Additional advertising space in the form of cross-sectional or longitudinal stretching devices could be allocated in the bottom under the string track structure. Furthermore, the bottom of a UST module is designed as a flat surface which provides additional space for advertising signs and pictures and in this case a string track that is visually “transparent” will not dominate at the second level.

- Buses and trolley-buses are the main sources of destruction of the asphalt-concrete cover of the city streets (because of the heavy load of the axis, frequent braking at the traffic lights and stops and high temperature of tires in summer when asphalt is also soften by the sun), and give rise to the creation of gages and asphalt swellings near the stops of public transportation.

- A tram track worsens the smoothness and rigidity of the road surface and in the sites where sleepers are laid the road surface, as a rule, is made as a dismountable assembled road bed which gives rise to the increased noise from the passing-through motor transportation.

- Unlike trolley-bus and tram lines UST does not require the high-cost contact network made of deficient copper (that is in need of periodical replacement) with the relevant poles, stretching devices, electric insulators, power cables, electric substations.

- In UST it will be easier to catch passengers traveling without paying for a ticket because you have to pay not for the travel but for the entrance to the elevated stop (as in metro when you pay for the entry to the station).

Recoupment and profitability of a UST under city conditions

1. At the average 30-passenger capacity of a module, average trip length of 3 km, average travel speed of 30 km/hour (maximal speed at the stages is 80 km/hour) and 250 working days per year one driver will be able to carry along an urban UST route the following number of passengers per year:

$$n_{pass.} = \frac{30\,pass.}{3km} \cdot 30km/hour \cdot 8hours/day \cdot 250days/year = 600.000\,pass./year$$

   At the annual salary of a driver amounting to 250,000 rubles and the salary of the servicing staff per 1 driver in the amount of 500,000 rubles the share of the salary of the servicing staff of UST in the total cost of a ticket will be as follows:

$$C_{salary} = 750.000 rubles/year : 600.000\,pass./year = 1{,}25 rubles/pass.$$

2. To carry 600,000 passengers per year the amount of fuel consumed by 1 driver (the average engine capacity of a module including idle running such as braking and stops at the stations will be 40 kWt):

$$T = 40kWt \cdot 0{,}25l/kWt \cdot hour \cdot 8hours/day \cdot 250days/year = 20.000l/year$$

   At the cost of fuel amounting to 15 rubles/l the share of the fuel cost in the cost of a ticket will be as follows:

$$C_{fuel} = 20.000l/year \cdot 15rubles/l : 600.000\,pass./yeas = 0{,}5rubles/pass.$$

3. At the cost of a model 3-km long UST section of serial production (i.e. equal to the average trip length of passengers; several model sections could be combined to make a route of any length) amounting to 75 million rubles (or 900,000 USD/km) and amortization allocations in the amount of 2% per year (service life is 50 years) amortizations allocations for the route and infrastructure will make 1.5 million/year (for a 3-km section).

4. At the cost of a serial U-362 UST module (maximal capacity is up to 40-45 passengers) amounting to 2.5 million rubles and amortization allocations in the amount of 10% per year (service life is 10 years), amortization allocations for the rolling stock per 1 passenger are as follows:

$$C_{rollingstock} = 2.500.000rubles \cdot 0{,}1 : 1.680.000\,pass./year = 0{,}15rubles/pass.,$$

   where:

   1,680,000 pass./year – the number of passengers that will be carried by 1 module per year at two-shift operation and 350 working days of a module per year (15 days per year are spent for repair and prophylactic works).

The net cost of transportation and the earnings from the operation of a 3-km model UST section (for the ticket cost of 11 rub./pass.) are given in Table 2.

Table 2

Indicator	UST operational indices with regard to the number of tickets sold, million tickets per year			
	1	2	5	10
1 Net cost of passenger trip, rubles/pass.	4.10	3.30	2.80	2.50
Including:				
1.1. Salary of UST staff, rubles/pass.	1.25	1.25	1.25	1.25
1.2. Cost of fuel, rubles/pass.	0.50	0.50	0.50	0.50
1.3. Amortization allocations for the route and infrastructure, rubles/pass.	1.50	0.75	0.30	0.15
1.4. Amortization allocations for the rolling stock, rubles/pass.	0.15	0.15	0.15	0.15
1.5. Other costs, rubles/pass.	0.70	0.65	0.60	0.45
2 Income from the operation of a 3-km UST route (at the ticket cost of 11 rubles/pass.), million rubles per year	6.9	15.4	41.0	85.0

The data given in Table 2 show that a UST route is highly profitable even at a small passenger flow (1 million pass./year) because at the ticket cost of 11 rubles the income from each passenger trip will be 6.9 rubles at the costs of 4.1 rubles (profitability is more than 150%).

Thanks to the high profitability of UST operation it will be possible to produce its track structure, supports, infrastructure and the rolling stock at a higher, representative level the cost of which will be 2-3 times higher than that of the aforementioned economic-level alternative. For example, a string-rail body could be made of stainless steel (which will protect the rail against corrosion during the whole service life of a track structure and contribute to the attractive image of the route), each stop could be provided with elevators (to aid passengers with poor health and disabled people to climb to the second level); supports could be decorated with natural stone, etc. Furthermore, it is possible to design transportation modules with improved interior and decoration of a saloon, including climate control facilities, etc.

Construction of urban UST routes will provide profitable investment of capital for investors. For example, with 120 million rubles invested in a 3-km section of UST (1.4 million USD/km including infrastructure and the rolling stock) it will take the investor approximately 3 or 1.5-2 years to pay back his investments at the traffic volume amounting to 5 million and 10 million passengers per year, respectively. During the service life (50 years as minimal) a route will give the profit of more than 2 billion rubles at the initial investments amounting to 120 million rubles. For a cheaper design alternative of the economic level it will be possible to pay back the expenses quicker and to bring the higher profit for investor.
At small passenger flows it would be reasonable to use mini-UST (for traffic volumes up to 3 million pass./year) or micro-UST (up to 1 million pass./year). Such routes will be cheaper and their recoupment period will be shorter.

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