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Opportunities for Development of City Rail Transport System and Network in Nur-Sultan (Astana)

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ABSTRACT

This paper is mainly focused on the development of city rail transport system and network in Nur-Sultan, Kazakhstan. This capital city with population of ca. 1.05 million citizens relies only on buses in the topics of public transport. Unfortunately, these vehicles are not as efficient as needed, because of their capacity. In the rush hours they are often delayed and overcrowded, the 88 bus lines are indirect with complicated detours, therefore complicated and unclear. The high number of buses increases everyday congestions on roads. The city tried to solve these problems by their own ideas – BRT and LRT. The first idea (construction of BRT system) was abandoned and the second one (construction of LRT system) may not work as well as the people of Nur-Sultan could wish and use. In order to improve this situation, the analysis of current situation was made. Based on the results, the conceivable solution was purposed – replacing majority of buses with only 5 tram lines. The usage of trams could lead to lowering the number of buses and cars in the streets, thus making transportation faster, more comfortable and ecological.

Key words : Public transport, bus lines, tram lines, BRT, LRT

1. INTRODUCTION

The city of Nur-Sultan (former Astana, Akmola, …) is the capital city of Kazakhstan. It is situated in the northern area of the country by the Ishim River. Nur-Sultan became the capital city in 1997 and it is the second largest city in Kazakhstan after Almaty (former capital). The size of the area is 810.2 km^2. The relocation of the capital city has lead to massive increase of population from ca. 327 thousand to ca. 1.05 million of inhabitants.

The city suffers from serious transportation problems generated mostly by the main transport mode that is common for post-soviet countries – cars. The roads are typically very wide – the main streets often consist of 6 – 8 traffic lanes. The more space is given to the car drivers, the more cars are being driven everyday causing severe congestions especially during rush hours.

Land transport infrastructure has been a vital part of a city. Development of land transport infrastructure, through its immediate and roundabout impacts, has a course on the manageability of development and in general advancement of a nation. Aside from improving the network, the improvement of streets can open up to this point detached districts to exchange and speculate and venture up access to products, administrations, and work openings. These infrastructures have a positive and negative impression on the citizens of a country. Though it is for the general betterment of a nation, it also produces problems. Traffic congestions can have a great effect on peoples' behavior. [1-3]

2. PUBLIC TRANSPORT IN NUR-SULTAN (ASTANA)

One option how to deal with problematic congestions without charging extra fees for driving through the city or another unpleasant measurement is improving the public transport (PT) system, if possible. To do that it is first necessary to understand how it worked in the past of Nur-Sultan, how it works now and what the plans of the city are for the future [4].

2.1 Past

The first trolleybus lines in Astana were launched in January 1983. By 2000, there were 5 working routes (for scheme of the former trolleybus routes in Astana see Figure 1), all of them were intersected at 2 points - not far from the station at the Akzhaiyk – Pobedy and Birzhan Sala intersections, then scattered along parallel routes, partially overlapping

each other and again converged at the Kenesary – Valikhanov intersection, from where they scattered to 2 end points. This way, a connection was provided between the railway and bus stations, the city center and the new (built in the 80-90s) districts. The travel time from terminal station to another terminal station and back including the break for drivers on all routes was the same – 1 hour 18 minutes. Due to this, the interval on the tracks was 3 ~ 4 minutes on average [5].

After the city became the capital of Kazakhstan, a new city center was built on the left bank of the river. Passenger flows have changed and trolleybus routes have changed to correspond to them. In 2007, only route No. 4. (see Figure 1) served the routes of Zhezkiik LLP (formerly Akmolagorelectrotrans OJSC). In October 2008, trolleybus system was stopped due to the resulting electricity debt and was never resumed. Trolleybuses were placed in the depot, which was used for car service (2008 – 2015). In 2013, Kazakh and Skoda 14Tr trolleybuses were transferred to Petropavlovsk. Since February to March 2015, all the trolleybus depots were demolished and replaced by residential buildings [6].

Figure 1: The scheme of former trolleybus routes in Astana in 2008 (source: http://astana-trolleybus.narod.ru/map.jpg)

2.2 Current state of PT

Today's transportation system in Nur-Sultan, organized by ALRDT Company, includes buses, shared taxis, railways and airport. The PT consists (apart from shared taxis) only of buses.

There are 88 bus lines in total. They are sorted to 3 groups – city buses, suburban buses and express buses. Each group has a different color.

In this paper the authors focused mainly on the first group – city buses. They are the biggest and most complicated group.

A. City buses

This group consists of 61 lines. The color of vehicles is green. The minimum interval is ca. 11 minutes on average and the maximum is 17 minutes on average.

B. Suburban buses

There are 18 bus lines in this group. The vehicle color is blue. The minimum interval is ca. 29 minutes on average and the maximum is 73 minutes on average.

C. Express buses

The last group are the express buses of red color and they include 9 lines. The minimum interval is ca. 10 minutes on average and the maximum is 21 minutes on average [7].

2.3 Current state of PT

Following table (see Table 1) shows public transport options in selected capital cities in the world with similar population to Nur-Sultan (± 20 %). Namely metro, tram, trolleybuses and buses are mentioned. Majority of the cities offers their passengers at least one alternative public transport type to buses. The most common option to bus is metro, followed by trams. City rail transport system and network is commonly used in most of capital cities [8].

Table 1: Public transport modes in selected capital cities

City	Country	Pop*	Metro	Tram	Trolley	Bus
Belgrade	Serbia	1,17	NO	YES	YES	YES
Sofia	Bulgaria	1,24	YES	YES	YES	YES
Brussels	Belgium	1,19	YES	YES	NO	YES
Tbilisi	Georgia	1,16	YES	NO	NO	YES
Yerevan	Armenia	1,07	YES	NO	YES	YES
Nur-Sultan	Kazakhstan	1,05	NO	NO	NO	YES
Bishkek	Kyrgyzstan	1,01	NO	NO	YES	YES
Stockholm	Sweden	0,96	YES	YES	NO	YES
Ottawa	Canada	0,93	NO	NO	NO	YES
Amsterdam	Netherlands	0,87	YES	YES	NO	YES
*Population in millions of inhabitants						

In the last 10 years, new tram rails were built in "culturally related" country – Turkey. In Antalya, which has 1,2 mil. inhabitants, the city rail transport system is 15.4 km long, includes 15 stations since 2016. In Izmit (also known as Kocaeli), which has population only of 0.36 mil. only, the length of the city rail transport system is 7.4 km with 11 stations since 2017. It is very useful as it provides connection of the main bus station with the main railway station. For decades, tram is a traditional transportation mode in the city of Konya. It measures already ca. 21 km. In this city which has similar population to Nur-Sultan (1.22 million inhabitants) is being built another mode – metro. Since 2015 it is possible to travel around Malatya (0.77 million inhabitants) by BRT trolley. Originally, it was supposed to be LRT tram. Today's trolley lines are 17 km long and the city plans to build another 34 km. The best example of the city rail

transport system in Turkey is in Eskisehir with the population of 0,83 million. There is traditional tram traffic with branched network. It was opened in 2004 with the length of 14.5 km. The first trams there were by Bombardier Company and since 2018 there are also trams from Czech Republic delivered by Škoda Transportation.

Compared to the cities mentioned above, Nur-Sultan doesn't have well developed PT system. Buses shouldn't be the only mean of public transport in cities with more than one million inhabitants, as their capacity is low. Public transport in large cities with high population should include rail transport system as primary system and buses as secondary system. Trams are not as noisy as buses and they cause less vibration and they are more ecological.
Trolleybuses in combination with buses are recommended in cities with population between 30 000 – 50 000 people, trams in combination with trolleybuses in cities with population between 50 000 – 250 000 people, combination of trams, trolleybuses, city rail and buses in cities with population between 120 000 – 650 000 people. The main transport mode in cities with population of 650 000 – 1 000 000 should be city rail (rarely metro) supported by trams, trolleys and buses. Large cities with population over 1 million should use metro, trams, trolleybuses and buses.

The situation is critical. The only used public transport mode are buses. As it is not possible to satisfy the demand for transport by a reasonable number of buses (due to low capacity of the buses), there are so many of buses with so short intervals, that during rush hours they don't even fit in the bus stops and stand in 2 lines next to the stops (see Figure 2). Such behavior of drivers is not only uncomfortable for passengers, but it is also very dangerous, too. This situation recently led the city to place letters "Public Control: Stop at Bus Stop" on bus stops for passengers asking them to report stopping of buses in wrong places in order to improve the PT service.

Figure 2: Right and wrong ways to stop at bus stops displayed on bus stops for passengers asking them to report stopping of buses in wrong places (source: http://alrt.kz/news/244)

Another problem is that the bus lines are indirect with complicated detours therefore complicated and unclear to passengers (see Figure 3). There is no scheme of all the bus lines at the bus stops. At stops only schemes with lines of some buses can be found. A tourist has almost no chance to travel without difficulties. The buses often make various one way or both way circles on their ways through the city. For example, bus line no. 52 makes three circles, bus lines no. 17 and no. 64 two circles. Even after the implementation of transfer tickets the organization of bus stops and lines did not change. It is almost impossible to remember where which bus goes.

Recently a new rule was implemented – getting in a bus is possible only through the first door by driver. It leads to even more delays on bus stops and overcrowded PT vehicles.

Figure 3: Example of scheme of five chosen city bus lines in Nur-Sultan

On the other hand, since 2016 there is no conductor selling the tickets and checking ins and outs in the bus. Passengers use smart cards only to check in the vehicle with the possibility to transfer up to 90 minutes. This is a slight improvement in modernization of PT of Nur-Sultan.

3. NUR-SULTAN'S ORIGINAL PLANS FOR SOLUTIONS AND THEIR RESULTS

3.1 Unrealized plan of BRT system

At first, there was a plan to build BRT system and was supposed to be finished in 2016. Unfortunately, it never became true. The PT vehicles were meant to move in separated lanes equipped with closed passenger stations with platforms at the same level and underground passages. At first, 18 stations were supposed to be built and to connect airport, EXPO-town, Abu Dhabi Plaza and the new railway station (see Figure 4). Then their number would have been gradually increased. BRT stations would have been equipped with access security systems, an electronic payment system (based on the metro principle), escalators and elevators. Purchase and control of tickets would have been carried out

based on the metro. Payment for BRT fare would be done by using the electronic fare payment system. The stations were meant to be in two-levels: the first level – a pedestrian underpass, payment and access to control zones, technical rooms and the second – platforms, waiting areas, boarding and exits. The stops themselves should have been closed and the levels connected by an escalator, an elevator and stairs [9].

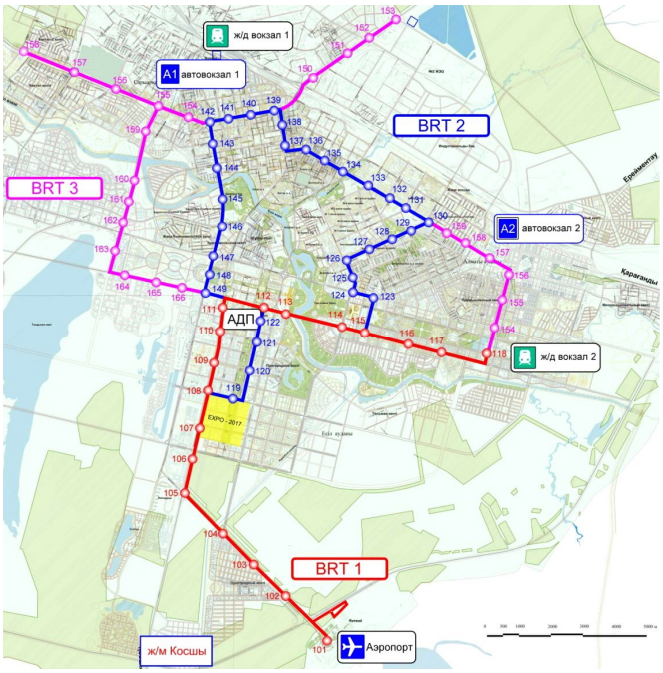

Figure 4: Scheme of planned, but unrealized BRT system in Nur-Sultan (source: https://tengrinews.kz/kazakhstan_news/opublikovan-marshrut-skorostnyih-avtobusov-BRT-v-astane-261403/)

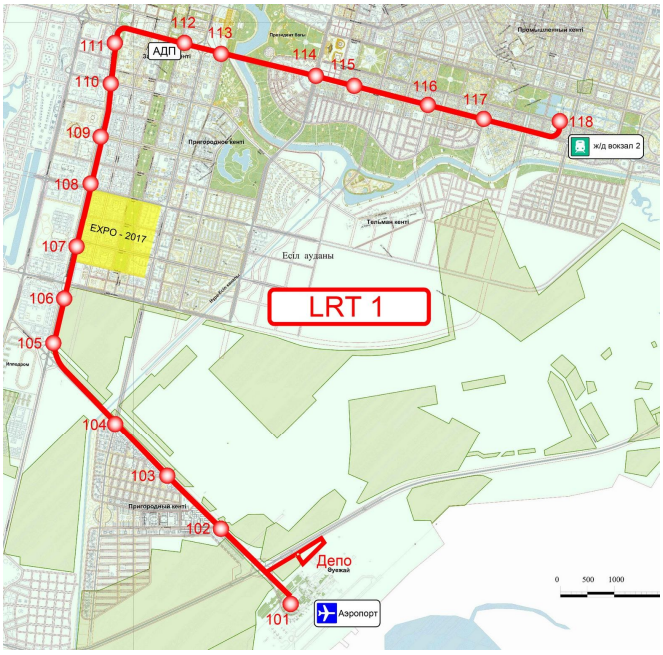

Figure 5: Scheme of 1 line of being built LRT system in Nur-Sultan (source: http://alrt.kz/smi/73)

The BRT system (see Figure 5) was planned very well as it would connect all the important places with highest transport demand. It would reach even entire city by using the wide streets and boulevards.

3.2. Currently being built LRT system in Nur-Sultan

Currently the LRT system is being built in Nur-Sultan (see Figure 4 for scheme of 1 LRT line only). This plan is clearly not as good as the plan of the BRT system, as it connects only the airport with the new railway station, being useful only to those, who are not interested in visiting Nur-Sultan. There is almost no use of it for the people of the city, as only a part of the line goes through the new city center, but doesn't connect the important places. It does not provide connection to the main shopping center Khan Shatyr or the old shopping center, or residential areas, or the old railway station. This is a huge problem as many trains still go through the old railway station and quite a lot of bus lines go there as well.

The LRT system will include a 100% flyover, 18 modern closed type stations, 19 rolling stock units and a depot.

Stations are built to be fully adapted to the climatic features of Nur-Sultan, equipped with electronic fare, alarm, heating, ventilation and air conditioning systems, as well as video surveillance (see Figure 6 for example of proposed LRT station design). The final length is planned to be 22.4 km. It was supposed to be finished by 2018, but in 2019 it's not yet ready for operation.

Figure 6: Example of proposed LRT station design in Nur-Sultan (source: http://alrt.kz/smi/73)

To avoid limiting of the car transportation the LRT is being built as an elevated road, so that its construction is very expensive (BRT would have been much cheaper). In addition, preference of car transport is obsolete approach. It is against today's modern cities principles at it is not ecological. Another con of elevated road is complicated adding of new branches and connecting to another rail mode, because it is not situated on the ground.

4. ANALYSIS OF CURRENT SITUATION AND PROPOSAL OF NEW CITY RAIL SYSTEM

The authors drew down the scheme of bus lines of the entire city and then analyzed 416 sections of streets used for bus lines. Unfortunately, Nur-Sultan has no data from public transport surveying, so the origin-destination matrix does not exist. The only accessible data are bus lines, their directions, general intervals of each line, types of buses (articulated bus or standard rigid bus), number of vehicles of each line and the length of each line. The authors expect that the current lines and intervals do respect basic origin-destination matrix in long term. Public transport supply represents the passenger capacity of buses of all lines going though the sections and stops in given period of time. It is the only usable accessible data about the passengers' flow.

4.1. Analysis of current state

First, based on the knowledge of the bus line intervals during rush hours and the capacity of buses of Nur-Sultan, the traffic volume of buses per hour for each line and then for each section was calculated as pointed in (1).

$$N = (60 / t_1) + (60 / t_2) + ... + (60 / t_n) \quad (1)$$

N .....traffic volume of bus vehicles per hour in each section in one direction
$i = 1, ... n$ ..bus lines coming through the section
t_i .....interval of bus line i in the section [min]

Afterwards the authors calculated the transport supply during rush hours for one (and later as well as both) direction in each section as pointed in (2).

$$S = N \times C \quad (2)$$

S .....public transport supply during rush hours for one direction [passengers / hour]
C .....capacity of typical bus used in PT in Nur-Sultan [passengers]

Figure 7: Categories of sections (related to public transport supply) of bus lines route network in Nur-Sultan analyzed by authors

The 12 m long buses with capacity of 95 passengers were considered for definition (2) and for bus lines with use of 18 m long articulated buses the result was recalculated for capacity of 159 passengers.

Then the authors sorted all 416 analyzed sections into 6 categories (A – F) based on their transport supplies in one direction. These categories are defined in Table 2. The scheme of sections sorted by categories based on their transport supplies can be seen in Figure 7.

Table 2: Transport supply categories applied for all 416 analyzed sections

Category	Public transport supply [passengers / hour in 1 direction]	Total amount of analyzed sections
A	> 10 000	4
B	8 000 – 10 000	12
C	6 000 – 7 999	32
D	4 000 – 5 999	49
E	2 000 – 3 999	89
F	< 2 000	230

In relation to traffic volume of buses and their section interval during rush hours at least the sections A, B and C clearly do require city rail transport system and network of higher capacity of vehicles.

4.2. Proposal of new city rail transport system

After the analysis of current situation in sections of streets of interest, the authors concluded that usage of trams as PT is the best and the most feasible solution of problematic transportation in Nur-Sultan.

Thanks to the wideness of streets and boulevards (with 6 – 8 road lanes) trams in separated lanes can easily fit to the most problematic areas without being limited by cars.

The authors suggest placing tram tracks in the sections belonging mostly to the categories with the highest current transport supply. They also focused on easy, fast and comfortable possibility to change from tram to LRT by leading the tram lines nearby LRT elevated road. The easily accessible LRT stations are namely numbers 118 and 116 (for details see Figure 4). The stations number 111, 112 and 113 are not far from trams too, it's only approx. 300 – 500 m. The authors kept in mind the idea of connecting all the important places in Nur-Sultan like for example railway stations, shopping centers, downtown or residential areas ... etc.

The authors conducted from the analysis of transport supply to propose 5 tram lines while keeping current supply. For that, the authors recommend to use trams of highest capacity, e. g. Bombardier flexity 2 (43 m of length) or for example CAF Urbos 2 or Huyndai Rotem with similar parameters (these trams are used in Turkey and they are less expensive than Bombardier flexity 2).

To find the best street sections for trams the authors calculated the minimum necessary intervals between trams (as pointed in (3)) to keep up with current supply in case of use of Bombardier flexity 2 (43 m long) vehicles.

$$T_j = 60 / (S_j / C_{TRAM}) \quad (3)$$

j .....analyzed section
T_j .....minimal required interval of tram (when use type of Bombardier flexity 2) in section j when satisfied with the existing transport supply in one direction [min]
S_j .....current public transport supply in section j during rush hours for one direction [passengers / hour]
C_{TRAM} .....capacity of tram (calculated 380 passengers / tram for modern 43 m long Bombardier flexity 2)

The results of the calculation showed, that in case of using tram Bombardier flexity 2, the required intervals of trams during rush hours (as pointed in (3)) largely corresponded with previously defined categories of sections – the results are shown in Table 3.

Table 3: Required intervals of trams during rush hours for defined transport supply categories

Transport supply category	Required interval [min]
A	2
B	2 – 3
C	3 – 4
D	4 – 6
E	6 – 12
F	> 12

The scheme of tram lines proposed by authors can be seen in Figure 8. Tram line no. 1 (with interval 5 min. in one direction proposed by authors) is situated in streets Prospect Manggilik El, Sarayshyq St., road P-3, Respublika Ave., M-36 and Beibitshilik St. Line no. 2 (with interval 5 min. in one direction proposed by authors) goes through Syghanaq St., Turan Ave., Prospect Manggilik El, Qanysh Satpaev St., Qazhymuqan Munaytpasov St., Tauelsizdik Ave., Aleksandr Kravtsov St., Shokan Valikhanov St., Yqylas Dukenuly St. and Beibitshilik St. Line no. 3 (with interval 4 min. in one direction proposed by authors) starts in Sharbaqty St., followed by Yubileinaya St., road M-36, Raqymjan Qoshqarbayev Ave., Shakarim Kudayberdiuly Ave., road M-36 again, Sembinov St., Säken Seyfullin St. and ends in Zhenggis Ave. The beginning of line no. 4 (with interval 4 min. in one direction proposed by authors) is set in Magzhan Zhumabaev Ave., the line then goes through Bauyrzhan Momyshuly Ave., road M-36, Qazhymuqan Munaytpasov St., Tauelsizdik Ave., Aleksandr Kravtsov St., Respublika Ave., road M-36 again, Säken

Seyfullin St., Zhenggis Ave. and ends on road M-36. The last line called no. 5 (with interval 6 min. in one direction proposed by authors) begins in the same streets as like no. 2 – Syghanaq St., Turan Ave. Unlike no. 2, it doesn't turn to east but continues to north, after crossing the Ishim river line no. 5 turns to the east going through Kenesary St., then joins lines no. 1, no. 3 and no. 4 on road M-36. Then continues through Shakarim Kudayberdiuly Ave. with lines no. 3 and no. 4. Line no. 5 ends in the same street as no. 3 – the Zhenggis Ave.

The lines are supposed to be using existing streets and bridges. However, in order to connect lines no. 3 and no. 4 to LRT, it would be necessary to lengthen the Sharbaqty St. and Magzhan Zhumabaev Ave. to the south through green areas or at least add tram rails there.

The proposed lines guarantee easy, fast and comfortable possibility to transfer from tram to LRT and connection of all the significant places like residential areas, shopping malls, railway stations, university area or downtown. The tramlines connect the old north-west part and new south-east part of Nur-Sultan using the sections of streets with the highest current supply (see Figure 7). The key benefit of this network is safety and there are many other advantages, they are eliminating congestions. The authors in [10] made effort to avoid unnecessary conjunctions of the tramlines (see Figure 8).

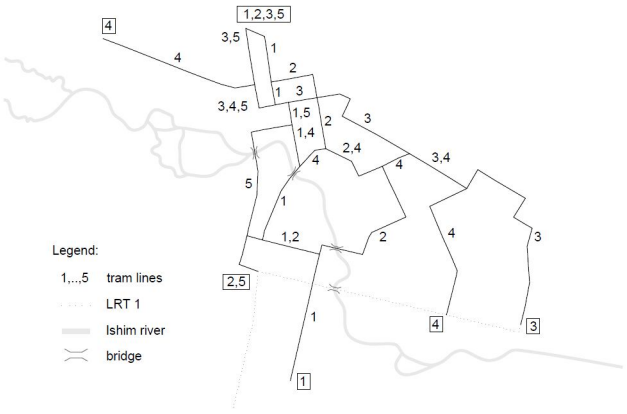

Figure 8: Scheme of tram lines in Nur-Sultan proposed by authors

To calculate the interval between trams of all lines in sections the following definition (4) was used.

$$T_s = 1 / ((1 / t_1) + (1 / t_2) + ... + (1 / t_n)) \quad (4)$$

T_s .....track interval between trams in section s in one direction [min]
$k = 1, ... n$ .number of tram line in section
t_k .....proposed interval of tram line k [min]

The scheme of proposed tram lines in Nur-Sultan with marked track intervals is shown in Figure 9.

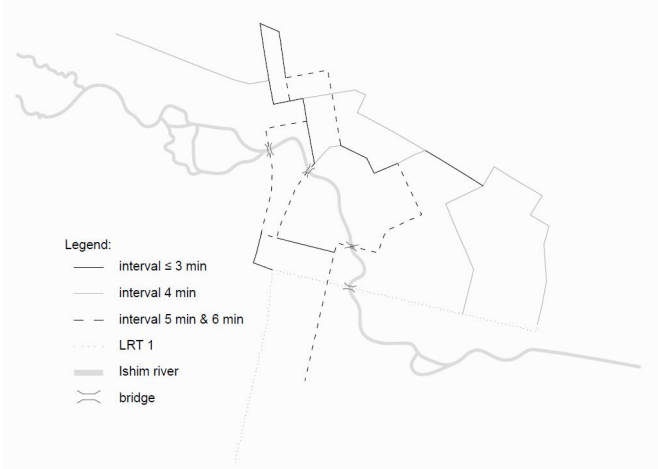

Figure 9: Scheme of proposed tram lines in Nur-Sultan with marked track intervals

The tram stations design could be similar to the design of stations of the abandoned plan of BRT. The payment system would be similar to metro principle – check in before entering the platform and no check out while leaving. There would be a possibility to purchase a transfer ticket to change not only between tram lines but also from a tram to a bus with time limitation. Another option would be an electronic smart card usable for all kinds of PT of the city. Stations would be roofed to protect the passengers from the unpleasant weather like rain or wind. There would be a pedestrian underpass underneath of the rails to increase safety of the passengers. It would be equipped with security cameras, stairs and elevators.

5. CONCLUSION

The authors analyzed current situation of public transport in the city of Nur-Sultan, Kazakhstan and suggested opportunity to improve PT by developing city rail transport system and network by trams.

The authors found the sections of the streets where the transport supply was high and proposed in total five different tram lines on them. For case of using the vehicle with highest capacity (Bombardier flexity 2) the necessary intervals were calculated.

The main benefits of the authors' proposal are lowering the number of buses in streets by using vehicles of higher capacity, faster and more comfortable PT by using separated lanes for trams and possibility of lowering the number of cars in streets leading to more ecological traffic. These would improve the quality of life of the citizens of Nur-Sultan. The negative of building the new city rail traffic system and network is the high cost of rails. However construction

of the tram rails on the surface of the streets is surely much cheaper than LRT on elevated roads, especially when the LRT plan doesn't connect all the important places so the demand of transport would always be low – LRT will never be used enough – it is a waste of money, unless the city would build many more elevated roads connecting the rest of the city of Nur-Sultan. This would not be economical at all.

The suggested change in PT of Nur-Sultan – trams, may encounter sociological problem (common in post-soviet countries) – fear of the limitation of car transport. This fear often leads to illogically situated city rail transport systems and networks outside the main streets or even demolishing of tram rails in many towns. If Nur-Sultan wants to be a part of the modern world, this attitude must be changed. The proposed tram lines are often situated in sections of streets, where bus-only-lanes are situated; therefore replacing them with tram rails (tram-only-lanes) would have no "negative" effect on car transport in these streets. As the lanes of the main streets of Nur-Sultan are generally very wide with high number (6 – 8) of wide lanes it shouldn't be a problem to narrow the lines a bit (to 3.00 – 3.25 m; these lane dimensions are common in European towns) or demolish a lane or two to get more space for separated tram lane. Public transport moving on separated lanes is faster, as it is not so influenced by other vehicles. That makes public transport more attractive. If more people used public transport, then there would be fewer cars so that less road lanes would be needed. In some parts of the streets it would also be possible to place the rails in the green areas next to the road. However, damaging green areas and replacing them with concrete or asphalt surface whenever there is another option left is an obsolete approach, which does not belong to the modern world. In European countries constructing separated lanes for public transport is a common approach. These lanes belong to public transport preference (priority measures). It is the tool to manage traffic flow increasing the quality of public transport service.

The proposed tram lines are situated in similar location as the BRT system was planned to be. This leads the authors to conclusion that the analysis and results of this study are correct and that leaving the idea of BRT and building LRT instead is even worst mistake, then the authors thought before the analysis. The authors believe the developing of city rail traffic system and network of Nur-Sultan by trams is a wholesome change and a huge step forward to the modern civilized world.

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