May, 28-29, 2019, Ternopil, Ukraine

ICCPT 2019: Current Problems of Transport: Proceedings of the 1st International Scientific Conference, May 28-29, 2019, Ternopil, Ukraine

Possibilities of using bus rapid transit in cities with dense construction area

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Abstract: Bus rapid transit (BRT) is one of the most popular mass passenger transportation systems as it is cost-effective, comfortable and rapid during its use hence it is widespread in developing countries. In the paper, the classification of urban public transport modes is highlighted and the main components of BRT system are given. Also, types of running ways on highways and other urban streets are classified and also measures about giving the priority to public transport in mixed traffic are given.

Keywords: bus rapid transit, running ways, cities with dense construction area.

1. Introduction

In view of the rapid rate of motorization level growth many countries develop different strategies about transport systems development. These strategies cover legislative decisions and implementation of normative acts on the government level, organizational decisions on local levels and also engineering decisions about the construction of new roads and reconstruction of existing ones.

To the question of public transport operation improvement, a lot of publications are aimed recently. Particularly, authors [1-5] investigate the influence of transit ridership and passenger flows on the effectiveness of bus rapid transit functioning. Some publications emphasize on safety, capacity, and reliability of public transit systems [6-10, 15]. Special attention is paid to allocation of bus lanes [11] and giving the priority to public transit on intersections [12].

To the measures which are implemented in different large cities of the world for the development of effective transport infrastructure are related [12]:

- reconstruction and redevelopment of existing transport infrastructure;
- possibilities of parallel street usage;
- construction of transit highways;
- differentiation of traffic on local and highway;
- change of movement direction on lanes during the day;
- change of traffic management during peak periods;
- renewal of traffic light signal system;
- construction of new roads;
- restriction of entry to the city central part;
- creation of toll roads, increase of fines for a traffic violation;
- limitation of sold automobiles amount and complicated system of buying cars;
- creation of a car sharing system;

Peer-review under responsibility of the Scientific Committee of the 1st International Scientific Conference ICCPT 2019: Current Problems of Transport

- improvement of traffic management;
- implementation of restrictions for different modes of transport;
- usage of automobiles on even and odd days depending on the last number on license plates;
- usage of Intelligent Transportation Systems for traffic control and management.

The usage of one or the other organizational measures depends on country legislation. What concerns engineering measures, their implementation quite often is impossible because of the existing dense construction area. That is why in such cities it is necessary to use such transport systems in which preference is given to public transport, cycling and walking. To encourage citizens to use public transport, first of all, it is necessary to develop such a system which would be cost-effective for the city and also cheap and comfortable for usage by passengers.

To the public transport systems can be included bus, tram and trolley-bus transportation, subway, light rail transit and bus rapid transit and also suburban transportation. In Table 1 are given the main characteristics of public transport modes.

Among the most effective public transport systems can be highlighted subway, light rail transit and also BRT. Their main features are high transportation capacity, cost-effectiveness and also the existence of separated rights of way for vehicle movement which reduces travel time for passengers and increases the operating speed of vehicles. But construction of subway and light rail requires high economic costs and an area that is necessary for tram lanes allocation and also a big capital investment on underground lines construction. On the contrary, BRT is relatively cheap as they do not demand the construction of special pavement for bus movement that is why they are especially effective.

Table 1. General characteristics of public transport categories [14].

Public transport category	Typical location of public transport stops	Running ways	Service frequency	Buses/trams
Local	From 100 to 400 m, sometimes on request	Movement in mixed traffic	1…20 units per hour, depending from time of day	Local bus/tram
Local/ Express	The same as local but with small amount or without stops in express zones	Movement in mixed traffic in local connection, in express-zones possible full segregation from the rest traffic flow	The same as local but can serve only in peak periods as additional to local	Local bus/tram
Semi rapid	From 300 to 1000 m	Mainly partial separation from the rest traffic flow, possible full segregation from the rest traffic flow or movement in mixed traffic	4…8 units per hour, sometimes more	Typically articulated bus/high-capacity tram
Rapid	From 400 to 2000 m	Exclusively separated movement from the rest traffic flow	4…30 units per hour	Typically articulated bus/light rail (metro)
Rapid/ Suburban	As rapid in dense city areas; as suburban in all other cases	Exclusively separated movement from the rest traffic flow	4…8 units per hour on branches	Suburban bus/light rail (metro)
Suburban	More than 2000 m	Exclusively separated movement from the rest traffic flow	1…4 units per hour on branches	Suburban bus/suburban rail transport

The main difference between the urban tram system and BRT is that last can provide high-quality service of passengers with quite low costs, the price of which for the city can be from 4 to 20 times lower than light rail transit systems and from 10 to 100 times lower than subway [13].

Institute for Transportation and Development Policy gives the following definition of BRT: a high-quality bus-based transit system which carries rapid, comfortable and cost-effective urban transportation due to separated running ways, rapid and frequent operations and also excellent marketing and client service [15].

BRT system consists of such main components [16]:

- separated running ways;
- specially equipped stations;
- highly articulated vehicles;
- high-quality service;
- effective fare system;
- usage of Intelligent Transportation Systems.

In cities with dense construction area, the main problem is the allocation of separated running ways.

2. Materials and methods

Differentiate such types of running ways which can be implemented during the development of BRT system [17]:

- physically segregated ways for bus movement;
- highway lanes;
- urban streets.

Physically segregated ways for bus movement are effective during their usage because they totally separate bus movement from the rest of the traffic flow, moreover not only on sections between intersections and also on intersections. But their main drawback is that for construction of such running ways additional area is required which makes them impossible to use in cities with dense construction area.

Highway lanes can have such forms: median busways, high occupancy vehicle lanes and curbside bus lanes [17].

Considering urban streets, there the most spread forms are median busways, bus lanes and mixed traffic lanes [17].

Median busways are effective, but their usage is justified with bus intensity from 60 to 90 units per hour in one direction in peak periods with minimum bus volume 600 units. Besides, their implementation requires widening of existing roadway which is not always possible with high traffic intensity and existing dense construction area [18].

One more variant for giving the priority to public transport is the allocation of bus streets for bus movement. But such a decision is possible in the condition of existence parallel by-pass streets.

Table 2. Recommended bus volumes for bus lanes allocation [18].

Type of bus lane, located on the curbside	Minimum daily bus volume, units	Range of movement volume per hour on one direction in peak periods	
		Buses, units	Passenger, persons
Concurrent flow movement:			
in city central part	200	20-30	800-1200
outside city central part	300	30-40	1200-1600
Contra-flow movement:			
short segment	200	20-30	800-1200
extended segment	400	40-60	1600-2400

Bus lanes can be located on the curbside or in the lane which is adjacent to the curbside. The last case allows the placement of parked vehicles and also the arrangement of right turn without conflict with the bus movement. Also with the allocation of bus lanes in the curbside, it can be possible to arrange bus movement in concurrent and contra-flow directions. In Table 2 it is given recommended bus volumes for allocation the certain lane type.

The main condition for the allocation of separated bus lanes is the existence of enough number of lanes. Authors [19] note that the main factor which determines the possibility of bus lanes allocation is the number of persons who travel by public transport relative to the number of persons who use private transport. They propose such determination of bus lanes implementation possibility:

$$q_B \geq \frac{q_A}{N-1} x \,, \tag{1}$$

here q_B and q_A – hourly bus and automobiles intensities relatively; N – the general number of lanes and x – average bus to automobile occupancy ratio.

In general, if the lane is allocated for buses and these buses carry the same amount of passengers as automobiles on adjacent lanes than bus lanes are warranted [19].

Author [20] indicated that in cities central parts advantages of allocation separated bus lanes are significant. Research in Thessaloniki city, Greece, shows that bus travel time reduced by 21.2% during the morning peak period and by 26.1% during the afternoon peak period. Fuel consumption reduced by 24.22% and 28.32% respectively during morning and afternoon periods. The average bus speed increased by 4.35% and 11.57% respectively for these periods. At the same time, the average speed of traffic flow reduced (respectively by 0.82% and 0.59%) and traffic delays increased (respectively by 1.71% and 0.06%).

Author [21] notes that on congested streets separated bus lanes can twice or three times increase bus speed (Figure 1).

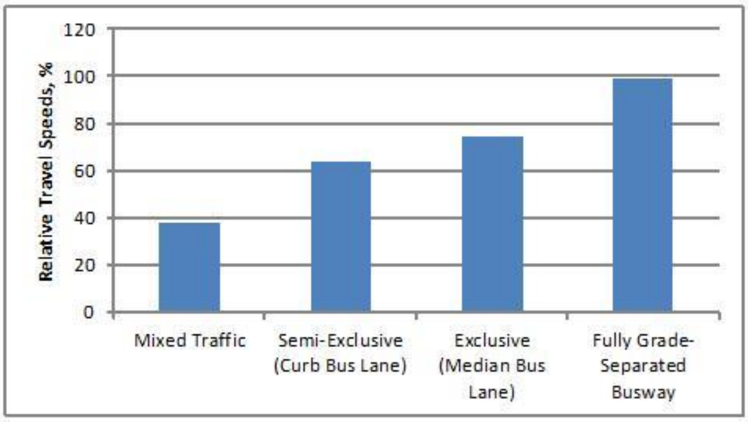

Figure 1. Relative bus speeds with a different implementation of running ways [21].

But, the negative moment is the approach of the bus lane to the city central part where there is no possibility for broadening the running way. Authors [17] name it “the last kilometer” when public transport from an existent bus lane is forced to flow into the general traffic flow. In such case, several variants are possible for allocation the temporary lanes for public transport movement: bidirectional bus lanes, reversible bus lanes and also separated bus lanes only in peak periods. Such variants are not optimal and can be used only in cases when other strategies are impossible to implement.

The other variant is the implementation of the so-called “dynamic” bus lane. Its essence lies in the fact that the lane can be used as common for traffic flow and buses, but on the edge of the lane are located special sensors which began to glow with the approaching of the bus and notify drivers that they should change the lane and give the way to buses. Such a strategy also is not optimal because, in places where traffic intensities are high, additional traffic delays can appear which can cause respectively public transport delay.

So, benefits for bus lanes allocation are evident, but the main problem is places where their usage is impossible. That is why in mixed traffic it is necessary to implement measures about giving the priority to public transport.

3. Results

During the movement in mixed traffic delays, in general, can appear on intersections. As Intelligent Transportation systems are an inevitable part of BRT system functioning, then determining the location of the bus using GPS is not a problem. That is why the urgent measure is giving the priority on intersections with the use of traffic light system during approaching to them public transport [22].

Authors [24] highlight such strategies during public transport movement on intersections:

- firstly, differentiate active and passive priority. Active priority includes determining and regulation of transit transport passage in real time, while passive priority includes such measures as optimal traffic light cycle, green time distribution and coupled control usage;

- secondly, priority strategies can be classified as total, partial and relative priority. Under total priority control program tries to give the bus null delay. Under partial priority means extended or early green time. Under relative priority, buses receive priority in movement only when traffic intensities are low;

- thirdly, differentiate unconditional and conditional priority. Unconditional priority means that all buses are given the priority. For the determination of total, active and unconditional priority use the definition absolute priority. Conditional priority means that buses demand priority only when they are behind the schedule;

But the main condition for giving the priority to public transport on intersections is the creation such road conditions during which traffic jams in general traffic movement would not appear.

Authors [23] allocate 8 scenarios of active priority which are given on Figure 2, during the approach of public transport to the intersection on different stages of traffic light cycle duration.

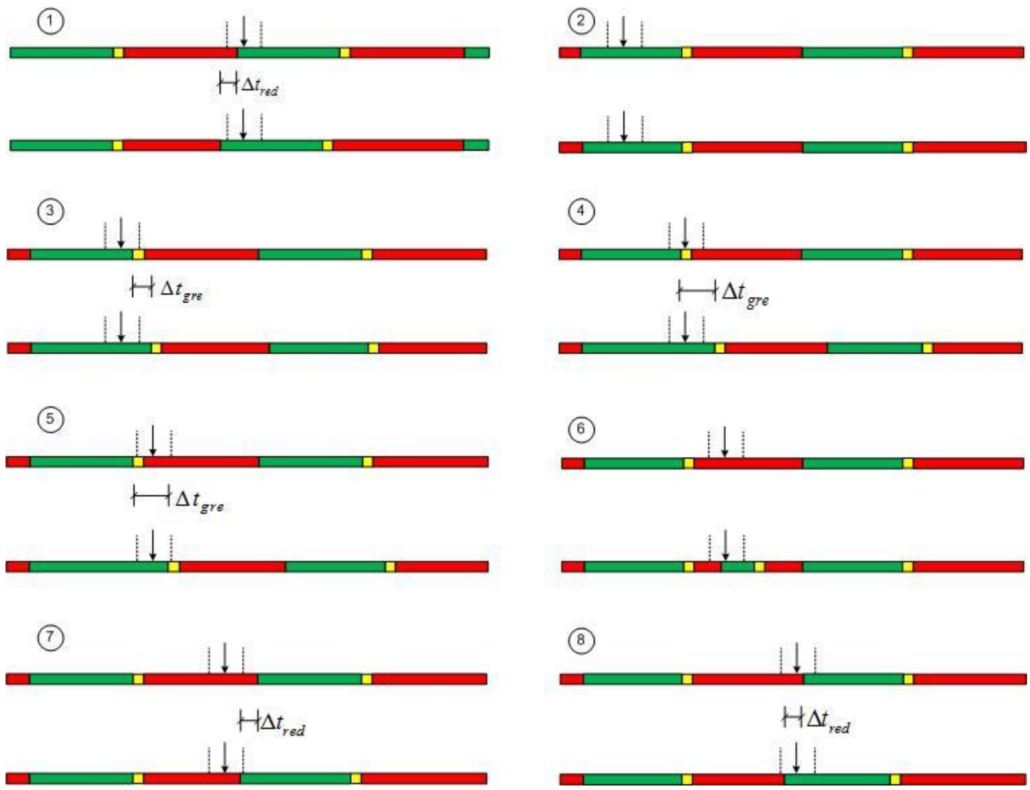

Figure 2. Scenarios of active priority for public transport on intersections [22].

Also to the measures about giving the priority to public transport on intersections can be related so-called by-pass lanes before intersections. Such lanes can be right turn lanes: at the moment when bus approaches to the intersection from this lane and the red traffic light signal is on, passengers board and alight. Then bus receives green before other vehicles for a few seconds. After that green traffic light signal turns on for the rest vehicles in the given direction (Figure 3, left). Another scenario is location the bus stop in the far side. When the bus approaches to the intersection, the green light turns on and bus passes the intersection a few seconds earlier than other vehicles, and then passengers board and alight on the bus stop (Figure 3, right) [18].

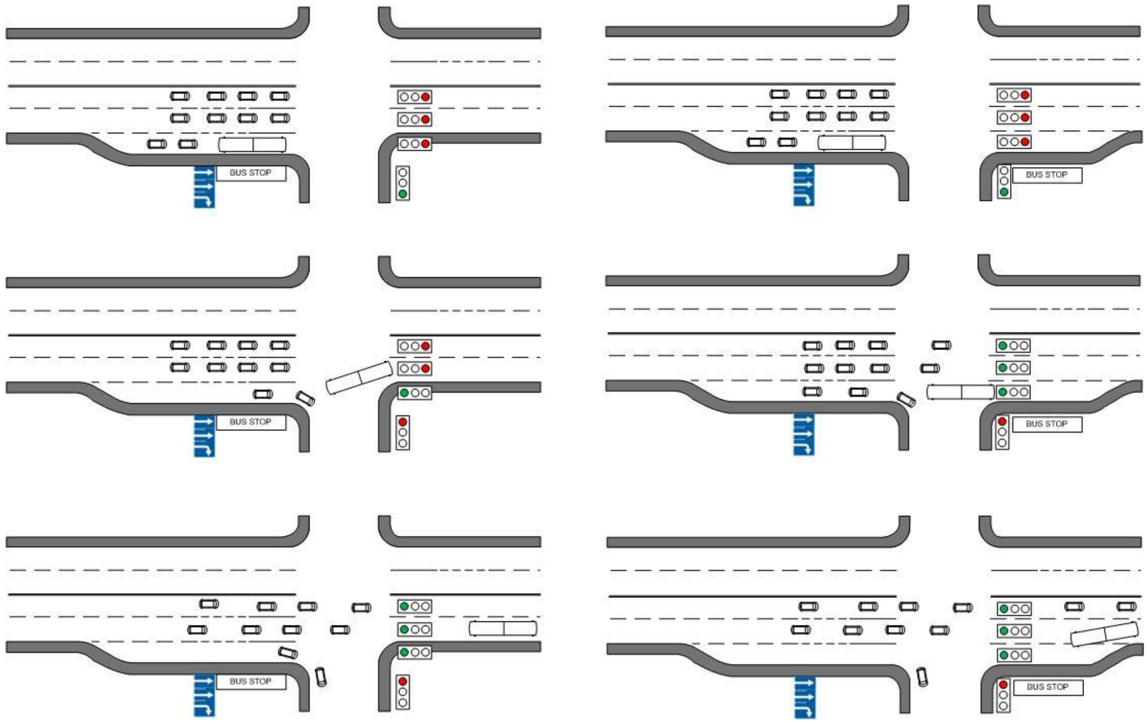

Figure 3. Usage of right turn lane as bus by-pass lane on intersections [18].

To the other measures for giving the priority to public transport relate parking restrictions on the curbside and in the middle of the roadway that will allow to allocate additional place for bus lanes allocation; turn restrictions on intersections that will decrease the amount of conflicts between turn traffic flows and buses that move straight in the case if separated bus lanes are located in the middle of the roadway.

4. Discussion

The peculiarity of the road network of Lviv city is the fact that the city has historically formed network that has a radial-ring planning scheme. On radial directions to the center go arterial streets. The disadvantage is that with the approach to the center the width on these streets reduces. Such a situation negatively reflects on traffic movement: in peak periods almost on all arterial streets traffic jams appear. On arterial streets, public transport routes exist which connect peripheral districts of the city with the central part. Other buses move on the routes that connect given radial directions.

Another negative moment is the fact that in the city public transport almost on all streets moves in mixed traffic. Individual cases of separated public transport movement from the rest traffic flow are known. For example, on Lychakivska st. and Kn. Olgy st., and also Chervonoi Kalyny av. a separated tramway exists. Also on sections of Svobody av. and Horodotska and Kopernyka st. separated bus lanes exist. The length of given lanes does not exceed 500 m. in every direction moreover after their end buses should flow in mixed traffic that creates additional delays in their movement.

Positive moment is the existence of traffic light systems on certain intersections of the city, where active priority in tram movement exists. But measures, counted before, are not sufficient for the effective functioning of public transport in the city.

With the aim of determination the strategy of city transport network development in Lviv city there was conducted questionnaire of citizens about the main directions of existing infrastructure development. It was carried out by the method of express-interview in different city districts. Sample size is 1100 respondents of four age categories: 20-35 years old; 35-45 years old; 45-60 years old and above 60 years old. Everyone could choose to three variants of proposed answers. Questionnaire results are given on Figure 4.

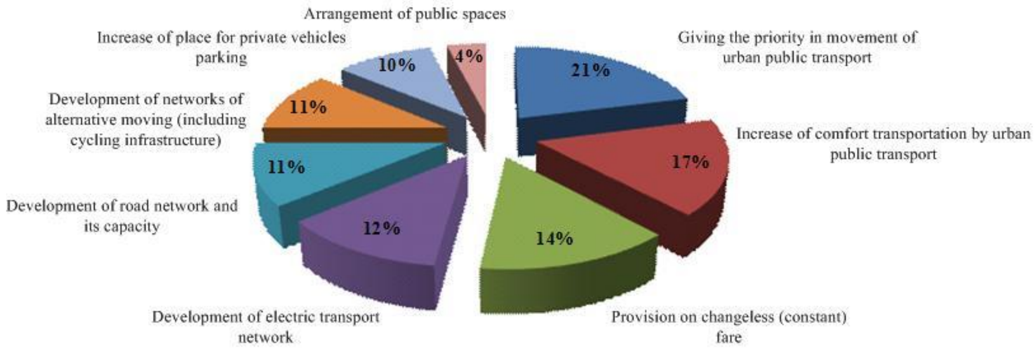

Figure 4. Priority of the main directions of city transport network development for citizens of Lviv city.

As it can be seen from the figure, great attention (38%) citizens of Lviv pay to the quality of transportation by the urban public transport, in particular giving it the priority in movement and increase of comfort transportation, although frequently the second is the derivative from the first as it includes speed of transportation. These questionnaires show that frequently fare cannot be in priority (for its temporary quantitative expression) if it will be backed up by the quality of service provision. Also topical is the task of development of infrastructure non-automobile moving, in particular electric transport, cycling, walking etc., which connects almost 27% of respondents.

5. Conclusions

Despite the high popularity of BRT systems, obstacles to their implementation still exist. One of such obstacles is complexity during designing the running ways in cities with dense construction area. But sources, analyzed in the article, point on the diversity of variants which can be used for giving the priority for bus movement. The most spread measures for giving the priority to public transport in cities with dense construction area is allocation the curbside bus lanes and also the usage of traffic light system with absolute priority for bus movement.

Results of conducted questionnaire show that 21% of city residents prefer giving the priority in the movement of urban public transport, and 11% – development of road network and its capacity in general. That is why, basing on the results of this questionnaire, and also given variants, the best solving the problem is a combination of organizational and engineering measures. Hence, in future it is necessary to carry out field research with gathering the data about traffic flows intensity on the streets where urban public transport routes exist, and also the volume of passenger flows. Received data will allow conducting further engineering solutions about giving priority to urban public transport.

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