Elaboration of a method's theory regarding the establishment and revision of bus lanes

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Abstract: Bus lanes should be integrated into the transportation network in an efficient way, while the location-specific features and the function of the certain section should be handled, too. The scope of this article is the *elaboration of a method*, which can help to determine, in which cases the establishment or existence of a bus lane is reasonable. With the method the processes can be analyzed in three steps: the arising *transportation demands* are handled, the questions of *feasibility* are reviewed, and the *expected traffic situation* after the establishment is estimated. The reasonable action in the section is calculated by the determination of the total time loss.

Keywords: bus lane, classification, traffic analysis, time loss calculation, establishment solutions

1. Actuality of the topic

The enhancement of the public transportation's competitiveness and the shift of the modal-split is an essential issue all over Europe [14]. Bus transportation plays a significant role in the execution of the urban public transportation [3], the quality of the transportation can be increased by its preference. However, these measures should be introduced cautiously in order to avoid their later revocations or modifications. The reasoned decisions [9] concerning the establishment of bus lanes have high importance, because an unconsidered decision may cause disadvantages for the participants of the individual transportation.

Some general aspects and threshold values can be helpful when making a decision. Although there are domestic and foreign guidelines for the establishment of bus lanes, they have plenty of deficiencies. The Transportation Research Board (= TRB) published a framework of aspects [7], which described the usage conditions of bus lanes. This paper reviewed a study called Austroads [1], in which the advantages of bus lanes are discussed in detail, but it contains no guidelines for the evaluation of them.

Taylor [10] provided an answer for this based on the work of Vuchic [13]. He states that the requisite of the establishment is, that at least as many passengers should pass through in the bus lane, as separately in the remaining traffic lanes. This indicator is based only on the passengers' throughput of an arterial section, and does not consider such factors, as the environmental impacts or the expectable changes of the modal-split because of the less time delay. It provides only an approximate estimation concerning the planned facility.

The TRB association published another study [12], which aimed the analysis of bus lanes on arterial sections. The bus routes are classified by the number of stops and the frequency, and then the infrastructural demands are assigned to the categories. However, this is still not a comprehensive solution, because the criteria of the establishment of bus lanes are only determined by the actual traffic situation.

Regarding the surveys found it can be obtained, that they have analyzed the establishment of the bus lanes from many aspects, but there are no such formulas, which can give a prognosis about the expected traffic situation and the advantages and disadvantages of the establishment.

2. The elaborated method

With the application of the method it can be determined, in which cases the establishment of a bus lane is reasonable. The method includes a three-step analysis, which is shown in the Fig. 1.

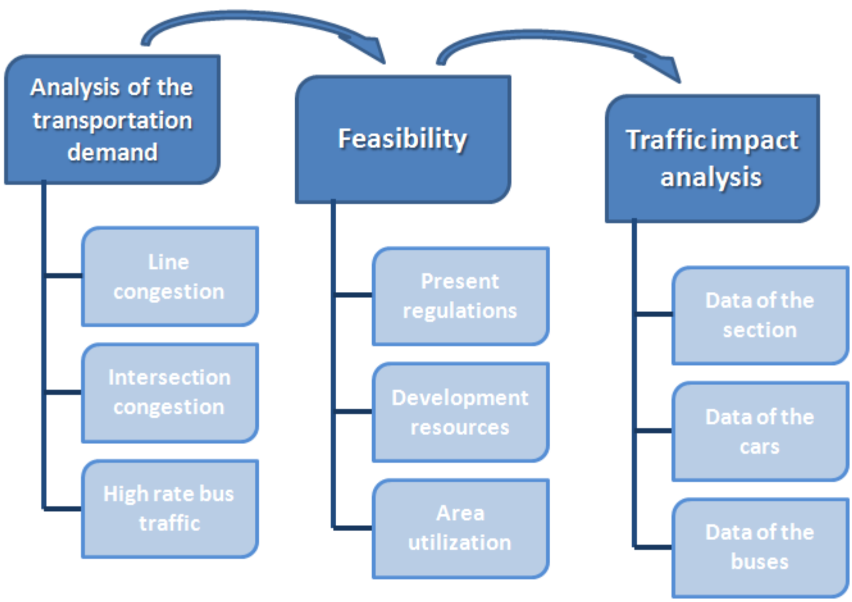

Figure 1: The three-step analysis of the method

As a first step the transportation demands of the public transport are analyzed, and then it is checked whether the conditions are met for the realization or not. At last in some cases the traffic impact analysis is needed to be executed, so that the changes in the time losses of passengers can be calculated on a certain section.

2.1. Analysis of the transportation demands

It is important to determine what is the type and amount of demand of the public transportation. Knowing the actual traffic situation on a certain section, it can be decided, whether the network structure is able to satisfy the expectations or not.

- *Line congestion:* When the public transport vehicles are forced to pass through slowly because of the other vehicles, e.g. congestion at a same level railway crossover, where the bus cannot turn in or reach the bus stop. In this case a separate bus lane could help.
- *Intersection congestion:* In the case of an otherwise undisturbed traffic situation an intense congestion often occurs close to the intersections. A short bus lane can mean time saving for the buses, which can be even a turning lane. An improved version is the intersection check-in system [11].
- *High rate bus traffic:* Independent from the traffic situation the establishment of a bus lane should be considered in case of high traffic sections, where the rate of the passengers travelling by bus is higher than 50% or the common frequency of the buses is under 2 minutes. Also the actual regulation handles this case distinguished [8].

2.2. Feasibility

With the analysis of the feasibility the regulation and financial frames can be determined, and the location-specific questions can be answered. Using these, the repartition of the road surface can be considered.

- *Present regulations:* In order to be able to decide among the versions, the technological parameters of the bus lanes should be known [6]. The Hungarian regulation determines only two threshold values [8], as “a bus lane can be assigned in an existing traffic lane, if at least 10 buses per hour pass through in the peak time, or if less than 10 buses per hour pass through in the peak time is typical, but the capacity in the most narrow point section is not decreasing because of the establishment.”
- *Development resources:* The infrastructure developments in the urban public transport in Hungary are realized by the contribution of the municipalities, and subsidies from the European Union are also available. Other support can be obtained from the government as a result of tenders.
- *Area utilization:* Concerning the realization another important aspect is the size and location of the certain network element. If the bus lane is established on the existing road surface, the requirements of the traffic facilities have to be analyzed. These are the sizes and features of the traffic lanes, parking lots, sidewalks and bicycle facilities, all of these are included in the technological road regulations.

2.3. Traffic impact analysis

When a solution without a significant effect for the traffic cannot be realized, the changes in the capacity of the section are needed to be analyzed. The question arises whether the modified performance of the section is sufficient to the rate, which is meant to be assured. For executing the traffic analysis the following data are needed:

data of the section:

- n – number of traffic lanes [piece],
- E – vehicle unit [piece],
- N – incoming number of vehicles [E/h],
- C – duration of peak hours [h],
- α_{jk} – ratio of right-turning vehicles [%] (only in case of an intersection),
- t_c – duration of the cycle time [s] (only in case of an intersection),
- t_p – duration of the red time [s] (only in case of an intersection),
- t_z – duration of the green time [s] (only in case of an intersection),
- L – length of the bus lane [m],

data of the cars:

- l_j – average queue length of the cars [m],
- l_b – average safety distance between the cars [m],
- t_k – average clearance time [s],
- N_{sz}– ratio of the cars in the traffic [%],
- u – average number of passengers [person],

data of the buses:

- k – number of buses per hour [piece],
- B – capacity of the bus [person],
- η – average utilization [%].

In the case of the section we take besides the characteristic traffic volumes (q_i) and the signal time plan (T, t_p, t_z) also the ratio of right-turning vehicles (α_{jk}) into consideration, because these vehicles do not pass through the remaining traffic lane, but they use the bus lane. The duration of peak hours (C) helps to determine the rate of the congested queue in case of heavy traffic.

The features of the vehicles are the queue length data (l_j, l_b) and their ratio (N_{sz}), which determines how many cars and how many trucks pass through. The average clearance time specifies how fast the vehicles leave the section. The average number of passengers (u) is needed to determine the total time loss of the passengers in these cars.

In the case of the buses from the given data (k, B, η) the total number and the total time loss of the passengers on the buses can be calculated.

3. Results of the traffic analysis

In our survey we estimated and calculated the expected traffic situation in a queue jump lane in an intersection arm, which is a bus lane assigned in an existing lane. With the analysis the loss times concerning the original and established statuses can be determined. After comparing the two values, it can be decided whether the establishment of the bus lane is suggested or not. We used the following assumptions:

- The time loss refers always to an average vehicle, which arrives during the middle of the red time, and waits in the middle of the queue, and arrives in the middle of the peak time.
- The clearance time of the vehicles is 0.5 s.
- The arrival of the vehicles in the intersection section is uniformly distributed.

3.1. Original status

Cars:

In the original status, when the bus lane is not yet realized in the section, the total time loss (eq. 1.) for the cars (T^a) is specified by the red time loss ($T_p{}^a$), by the clearance time loss ($T_k{}^a$), and by the eventually occurring congestion time loss ($T_t{}^a$).

$$T^a = T_p{}^a + T_k{}^a + T_t{}^a \tag{1.}$$

- car red time loss:

$$T_p{}^a = \frac{t_p}{2} * u * N_{sz} * N * \frac{t_p}{t_c} \tag{2.}$$

When calculating the red time loss ($T_p{}^a$) the car arrives during the middle of the red time (t_p) in the average case. Assuming uniform arrival and multiplying with the average number of passengers (u) the value for one person can be determined, with the N_{sz} ratio the same can be applied for the cars. This time loss (eq. 2.) occurs only to those cars, which have to wait because of the red sign.

- car clearance time loss:

$$T_k{}^a = \left(\frac{\frac{N * t_p}{3600}}{2} * \frac{1}{n} * t_k\right) * u * N_{sz} * N * \frac{t_p}{t_c} \tag{3.}$$

In case of the clearance time loss ($T_k{}^a$) firstly the number of appearing cars during one red time (t_p) can be determined. The car stands in the middle of the car's queue in the average case. In the case of more traffic lanes (n) the vehicles are distributed among the traffic lanes and leave the section with a predefined clearance time (t_k). The time loss (eq. 3.) for one person can be calculated as shown in eq. 2.

- car congestion time loss:

$$T_t{}^a = \left(\frac{\frac{N * t_c}{3600}}{2} - \frac{t_z}{t_k} * n\right) * t_k * \frac{3600}{t_c} * \frac{C}{2} * u * N_{sz} * N \tag{4.}$$

Congestion (eq. 4.) happens when the incoming traffic volume in the section is greater, than the maximal throughput of the section during the green time. In case of the congestion time loss ($T_t{}^a$) the number of cars have to be measured during the whole cycle time (t_c). We can assume here also an average case. The number of congested vehicles decreases during the green time (t_z) depending on the number of traffic lanes (n) and the clearance time (t_k). This time loss can be multiple increased during an hour depending on the cycle time (t_c). Because we considered an average car, which arrives in the middle of the peak hours (*C*), it waits only until the half time. The time loss for one person can also be calculated as shown in eq. 2.

Buses:

In the original status the total time loss (T^b) for the buses (eq. 5.) can be calculated very similar to the case of the vehicles (eq. 1.).

$$T^b = T_p{}^b + T_k{}^b + T_t{}^b \tag{5.}$$

- bus red time loss:

$$T_p{}^b = \frac{t_p}{2} * k * B * \eta * \frac{t_p}{t_c} \tag{6.}$$

When calculating the red time loss ($T_p{}^b$) in case of the buses, the bus arrives during the middle of the red time (t_p) in the average case. The value for one person can be calculated from the number of buses per hour (k), from the capacity of the bus (B), and from the average utilization (η). The time loss (eq. 6.) also occurs only, when the buses have to wait because of the red sign. The value is independent from the volume of the traffic.

- bus clearance time loss:

$$T_k{}^b = \left(\frac{\frac{N * t_p}{3600}}{2} * \frac{1}{n} * t_k\right) * k * B * \eta * \frac{t_p}{t_c} \tag{7.}$$

In case of the clearance time loss ($T_k{}^b$) the same calculation (eq. 7.) can be proceeded as with the vehicles (eq. 3.). Difference is only shown when calculating the time loss for one person.

- bus congestion time loss:

$$T_t{}^b = \left(\frac{\frac{N * t_c}{3600}}{2} - \frac{t_z}{t_k} * n\right) * \frac{3600}{t_c} * \frac{C}{2} * k * B * \eta \tag{8.}$$

The same (eq. 8.) can be stated during the calculation (eq. 4.) of the congestion time loss (T_t^b).

3.2. Established status

The traffic situation after the establishment can be defined using the following formulas. With them the amount of the time loss compared to the original status can be determined, as well as the characteristic threshold values. This approach does not take into consideration the negative externalities caused by the congestions, because it assumes the possibility of the modal-split's shift.

Cars:

In case of the established status the total time loss (eq. 9.) for the cars (T'^a) consists of the red time loss ($T'_p{}^a$), of the clearance time loss ($T'_k{}^a$), of the right-turning time loss ($T'_j{}^a$), and of the eventually occurring congestion time loss ($T'_t{}^a$).

$$T'^a = T'_p{}^a + T'_k{}^a + T'_j{}^a + T'_t{}^a \tag{9.}$$

- car red time loss:

$$T'_p{}^a = \frac{t_p}{2} * u * N_{sz} * N * \frac{t_p}{t_c} \quad (10.)$$

The red time loss ($T'_p{}^a$) is not affected by the establishment of a bus lane, so its value (eq. 10.) remains unchanged.

- car clearance time loss:

$$T'_k{}^a = \left(\frac{\frac{N*(1-\alpha_{jk})*t_p}{3600}}{2} * \frac{1}{(n-1)} * t_k \right) * u * N_{sz} * N * \frac{t_p}{t_c} \quad (11.)$$

In case of the clearance time loss ($T'_k{}^a$) the formula (eq. 11.) is very similar to the original one (eq. 3.), but from the number of arriving cars during the red time (t_p) the right-turning vehicles (α_{jk}) have to be subtracted, and one traffic lane less ($n–1$) is available for the cars.

- right-turning car clearance time loss:

$$T'_j{}^a = \left(\frac{\frac{N*\alpha_{jk}*t_p}{3600}}{2} * t_k \right) * u * N_{sz} * N * \frac{t_p}{t_c} \quad (12.)$$

The clearance time of the right-turning cars also have to be taken into consideration, because these cars pass through before the bus lane section with the other vehicles together. This formula (eq. 12.) differs from the car clearance time loss ($T'_k{}^a$) in the number of appearing cars and the number of traffic lanes is only one.

- car congestion time loss:

$$T'_t{}^a = \left(\frac{\frac{N*(1-\alpha_{jk})*t_c}{3600}}{2} - \frac{t_z}{t_k} * (n-1) \right) * \frac{3600}{t_c} * \frac{C}{2} * u * N_{sz} * N \quad (13.)$$

From the congestion time loss ($T'_t{}^a$) the right-turning cars (α_{jk}) also have to be subtracted, and one less traffic lane ($n-1$) is available for the cars. The other parameters remain unchanged (eq. 13.).

Buses:

In the established status the total time loss (eq. 14.) for the buses (T'^b) can be calculated as follows: from the red time loss ($T'_p{}^b$), from the clearance time loss ($T'_k{}^b$), and from the eventually occurring congestion time loss ($T'_t{}^b$), where compared to the original status (eq. 5.) the overload time loss ($T'_{tt}{}^b$) appears.

$$T'^b = T'_p{}^b + T'_k{}^b + T'_{tt}{}^b + T'_t{}^b \quad (14.)$$

- bus red time loss:

$$T'_p{}^b = \frac{t_p}{2} * k * B * \eta * \frac{t_p}{t_c} \quad (15.)$$

The red time loss ($T'_p{}^b$) is also not affected by the establishment of a bus lane, so its value (eq. 15.) remains unchanged.

- bus clearance time loss:

$$T'^{\,b}_{k} = \left(\frac{\frac{N * \alpha_{jk} * t_p}{3600}}{2} * t_k \right) * k * B * \eta * \frac{t_p}{t_c} \qquad (16.)$$

We should calculate with the clearance time loss (T'^{b}_{k}) only because of the right-turning vehicles (α_{jk}) in the bus lane, which is negligible in case of an overload, because when the average bus arrives to the end of the section, the vehicles have already left the bus lane. The other parameters (eq. 16.) can be handled as in the original status (eq.7.).

- bus overload time loss:

$$T'^{\,b}_{tt} = \frac{\left(\frac{N * (1-\alpha_{jk}) * t_p}{3600} - \frac{L}{(l_j + l_b)} * (n-1) \right) * t_k * k * B * \eta * \frac{t_p}{t_c}}{n * 2} \qquad (17.)$$

The overload time loss (T'^{b}_{tt}) can be observed, when more vehicles arrive during a red time, than how many can wait in the remaining traffic lanes parallel to the bus lane. Then the bus has to wait before reaching the bus lane. From the total number of vehicles arriving during one red time (t_p) those can be subtracted, which are waiting in the parallel traffic lanes (*n–1*), and it also can be divided by the number of lanes (*n*) beyond the bus lane, assuming that the vehicles are equally distributed in the available area. We consider the case of an average bus, which can wait anywhere in the congested queue randomly, that is why the result is divided by 2. The number of vehicles is the ratio of the length of the bus lane (*L*) and the area occupied by the cars (l_j+l_b). All this has to be calculated (eq. 17.) for one person and only for the red time periods.

- bus congestion time loss:

$$T'^{\,b}_{t} = \left(\frac{\frac{N * (1-\alpha_{jk}) * t_c}{3600}}{2} - \frac{t_z}{t_k} * (n-1) \right) * \frac{3600}{t_c} * \frac{C}{2} * k * B * \eta \qquad (18.)$$

When calculating the congestion time loss (T'^{b}_{t}) we can use almost the same formula (eq. 18.) as in the original status (eq.8.), because if there is a congestion, the bus has to wait with the other vehicles before reaching the bus lane. The right-turning vehicles (α_{jk}) also have to be subtracted, and there is one less traffic lane (*n–1*) available.

3.3. Calculating the total time loss

After the definition of the difference of the original (eq. 19.) and the established status (eq. 20.), the time losses of the passengers in the cars (ΔT^a) and in the buses (ΔT^b) can be determined.

$$\Delta T^a = T^a - T'^a \qquad \Delta T^b = T^b - T'^b \qquad (19.)$$

Summarizing these (eq. 21.) the total time loss can be specified (*T*).

$$T = \Delta T^a + \Delta T^b \qquad (20.)$$

- If this value is negative, then the establishment of a bus lane is suggested.
- If this value is slightly positive, then after reconsidering the transportation-political aspects the establishment can be realized disadvantaging the individual,

motorized vehicles. Still the possible congestions have to be taken into consideration, as well the shift of the modal-split in the direction of the public transportation.

- If this value is largely positive, then the establishment of a bus lane is not suggested, because in this case both the vehicles, both the buses suffer such a large amount of time loss, which can be not be justified.

4. Possible solutions

Four output opportunities may be expected (Fig. 2.) after the determination of the data stored. During the process we firstly analyze the conditions for the establishment of a new traffic lane. If the conditions are met, the new lane can be established (I. outcome). If it is not possible, then applying the area utilization parameters and the location-specific data the repartition of the road surface is tried to be realized. The result can be the II. outcome or the traffic impact analysis. On the basis of the elaborated formulas and the simulation data the III. or the IV. outcome can be produced.

- *I. Establishment of the bus lane in a new traffic lane:* If the establishment of the new lane is possible, then only land use planning aspects and correspondence with road regulations have to be considered during the planning process.
- *II. Establishment of the bus lane with the repartition of the road surface:* In this case some stored information is needed, which are the regulations and the data about the given section. Depending on the total width of the road surface and its planning class we can designate enough space for the bus lane with the change of the sizes and allocation of the traffic lanes, parking lots, sidewalks and bicycle facilities.
- *III. Assignment of the bus lane in an existing traffic lane:* The easiest and mostly used solution is the modification of the function of an existing traffic lane. In this case further data is required, some measurements have to be executed, and data has to be also collected about the vehicles in the traffic flow. Then with simulation techniques the expected traffic conditions can be predicted. The minimization of the time loss on the entire cross-section should be achieved.
- *IV. Alternative recommendations:* These solutions are recommended, when none of the above mentioned solutions is suggested. For example: bus lane on the tramway lane, HOV/HOT lanes [5] , dynamic traffic lanes [2], BRT [4] .

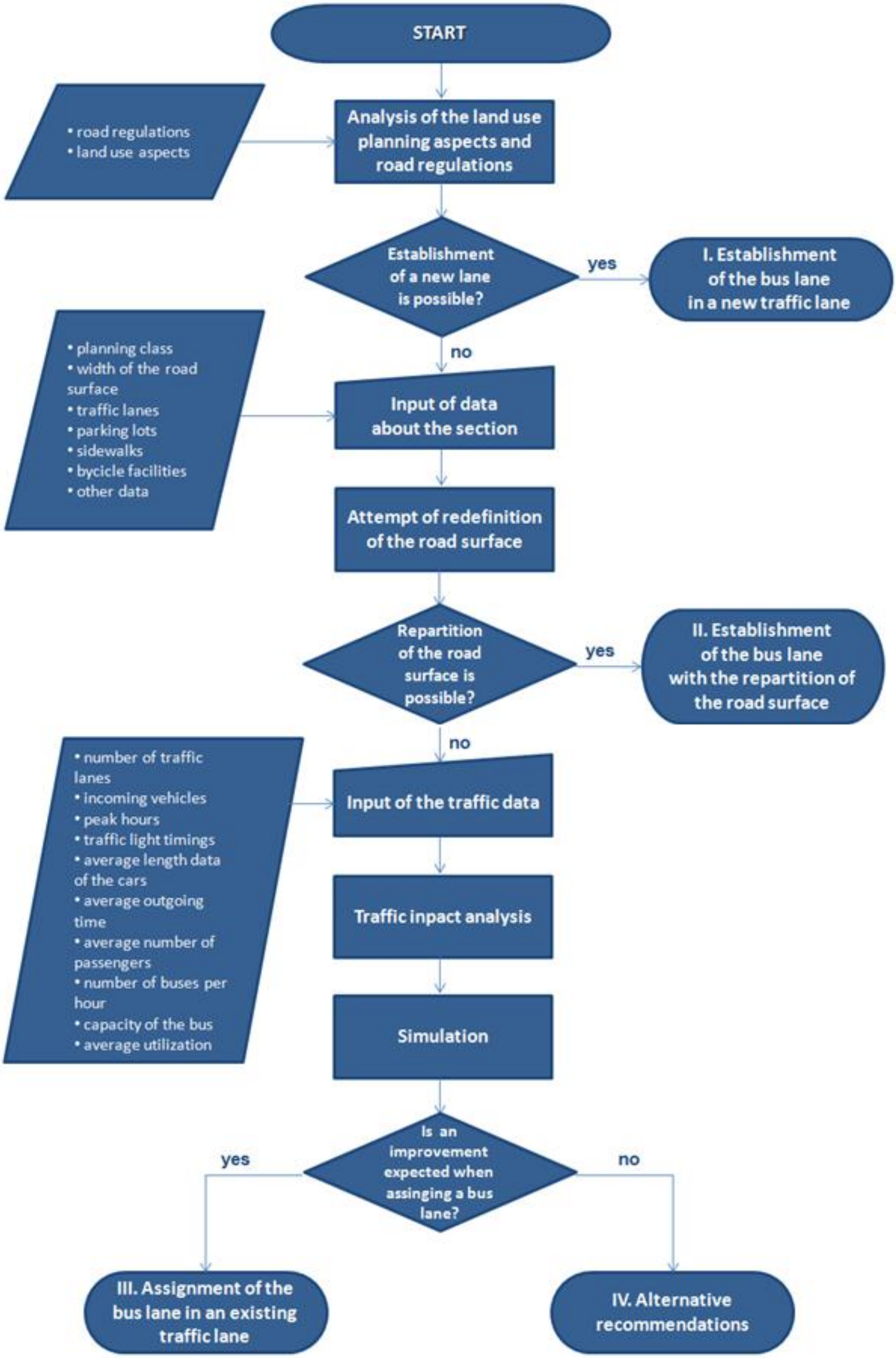

Figure 2: Block scheme of the method for the establishment of bus lanes

5. Summary

The present guidelines handle the problem with some significant simplifications, and the criteria of the establishment of bus lanes are only determined by the actual situation. We have elaborated a method, which supports the decision regarding the planning and establishing of a bus lane.

We have divided the problem into three steps, and presented four different solutions in case of a certain section. As a first step the transportation demands of the public transport have been analyzed, and then the conditions of the realization have been checked. The result of this step is a decision, which determines how the planned establishment should be realized: establishment of a new bus lane, repartition of the road surface or changing the functions of the existing traffic lanes.

In order to analyze the last case in details a traffic impact analysis is needed to be executed, so that the changes in the number of passengers can be calculated and determined. The aim is to reach the optimal throughput of the section by minimizing the total time loss concerning all the passengers. Knowing these results it can be determined whether the establishment of a bus lane is reasonable, and what kind of alternative solutions are presented.

The elaboration of the method's practical details and the validation of the formulas with a VISSIM simulation model is the next step of the research, which should prove the correctness of the model.

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