

1 Quantitative Assessment of the Bus Rapid Transit Efficiency in 2 Solving the Problems of Motorization of Modern Cities

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5

6 **Abstract**

7 The cause of congestions of traffic flow is its oversaturation with private cars. The fraction of
8 private cars within traffic flow exceeds 80

9

10 *Index terms—*

11 **1 Introduction**

12 The cause of congestions of traffic flow is its oversaturation with private cars. The fraction of private cars within
13 traffic flow exceeds 80% [1]. Another reason is the low utilization of private vehicles. In Moscow, according to
14 statistic, the average number of passengers in a car during rush hours is about 1.5 [1].

15 In this situation, the possibilities of public transport look very attractive. Vukan R. Vuchic, the wellknown
16 American scientist, underlines that city governments recognize urban public transport as the critical element
17 in achieving a balanced transportation system. In this case, "the support for urban transit provided by
18 federal/national and other levels of government have played a major role in its upgrading through research
19 and development, financing of a new system, new modes, and applied research for solving technical, operational
20 and planning problems" [8].

21 The possibilities of urban passenger transport in improving the transport situation of large cities are highly
22 appreciated not only by specialists in this field but also by prominent organizations, such as American Public
23 Transport Association (APTA). According to APTA technology for big cities public transit is Bus Rapid
24 Transit (BRT) enhanced with modern elements of ITS. In 2010 APTA issued a document «Implementing
25 BRT Intelligent Transportation Systems». It established recommended practices for incorporating Intelligent
26 Transportation Systems into Bus Rapid Transit Services and Infrastructure [7]. The document includes a very
27 helpful recommendation in general. But decision-makers need to calculated any planned activity in any particular
28 case and answer questions such as:

29 ? What are the problems to be overtaken? ? What is the goal of this activity?

30 ? What is the result to be achieved? ? What is another benefit? ? How much does it cost?

31 The nature of the answers for such questions needs to be not qualitative but quantitative.

32 The problem is that the highway is overload regularly during morning or evening rush hours and thousands
33 of people are stucked in traffic losing their time.

34 Here we consider BRT as a problem-solving tool. Our goal is to get a quantitative assessment of the Bus
35 Rapid Transit lane implementation efficiency considering a specific use case.

36 In this article, we'll try to discuss a situation with suburban service which occurs every morning and evening
37 on main highways between downtown and outlying suburban area. To be concrete, we assume that highway
38 length (L) connecting suburban area and downtown is 15 kilometers and it has eight lanes (l): i.e., four lanes in
39 each direction. Therefore, four lanes of highway from suburb to downtown are overloaded during morning rush
40 hours, and another four lanes from downtown to suburb overloaded during evening rush hours.

41 **2 Estimation of traffic flow parameters**

42 To obtain quantitative estimates, we will use the relations between the average speed and the average density of
43 the traffic flow, determined by the fundamental diagram. American scientists created the "following the leader"
44 theory and found out that in dense traffic flow conditions the relationship between the average speed (V) and
45 average traffic density (?) on a highway lane is expressed by the formula [5,6]:?? = ?? 1 ?? ??? 2 ?? (1)

3 REPLACEMENT POSSIBILITIES OF SEPARATED BRT LANE

46 We have conducted studies of Moscow highways to obtain parameters C_1 and c_2 in (1) expression for dense
47 traffic flow. We estimated that for traffic density ρ : $50 < \rho < 160$, the relationship between the average speed
48 (V) and average traffic density (ρ) one can express by the formula [2]: $\rho = 86V - 0.02V^2$ km/h (2)

49 According to equation (2), the density of the traffic flow one can express as follows: $\rho = 50(86V - 0.02V^2)$ veh/km
50 Let's assume that the average speed of dense traffic flow is 10 km/h. So our commuters spend
51 1.5 hours to reach downtown in the morning and another 1.5 hours to return home in the evening. Three hours
52 in total for transport every working day are unacceptable.

53 The density of dense traffic flow, according to equation (2) To solve the problem, we propose to organize
54 dedicated BRT lane, eliminating part of cars from traffic flow and carry passengers of eliminating cars by BRT
55 buses. Therefore, for this purpose one lane of the highway in each direction need to be dedicated to BRT buses.
56 In new conditions, only three lanes in each direction will be available for private cars.

57 3 Replacement possibilities of separated BRT lane

58 Let's introduce an "elimination coefficient" k as follows: (7) where: C_o -Average number of private car passengers
59 during rush hour period, passengers/vehicle C_{bus} -Capacity of BRT bus. $0 = C_o C_{bus} k$

60 The sense of the k coefficient is an average number of private cars, which one can eliminate by one BRT bus.
61 It depends on the average occupancy of a private car during the rush hour period. The mandatory condition
62 is that BRT bus not be overloaded during the trip. So, let's assume that during rush hours the bus passenger
63 load is not exceeded established normative value [3,4]. Then the total number of private cars (N_e), eliminated
64 during one hour period by dedicated BRT lane can be estimated as follows:

65 $kN_e = S_o$, we have: 1) For regular buses: $1080/91f_0 = 1080/67$, so $12f_0 = 16$ BRT buses per hour. In this
66 case the headway ($h_0 = 60\text{minutes}/f_0$) is estimated as follows: $60/16 = h_0 = 60/12$, so $3.75 = h_0 = 5.0$ minutes.
67 2) For articulated buses: $1080/127f_0 = 1080/93$, so $9f_0 = 12$ BRT buses per hour. In this case the headway
68 ($h=60\text{minutes}/f_0$) is estimated as follows: $60/12 = h_0 = 60/8$, so $5.0 = h_0 = 7.5$ minutes.

69 To be attractive, BRT buses must have Right of Way (ROW) Category (B) [8] that are longitudinally physically
70 separated lane by curbs. In this case, BRT buses movement not depend on traffic parameters. We suppose that
71 BRT bus maximum speed along the separated lane is 60 km/h. We suppose that to keep maximum speed value 60
72 km/h for the separated lane, headway for BRT buses must not be less than 2 minutes for safety and organizational
73 reasons which correspond to maximum frequency $f_{max} = 30$ buses per hour. So, we have the reserve of capacity
74 of BRT lane, which can be used to eliminate additional vehicles from another three lanes and to raise the average
75 speed of dense traffic flow on regular lanes.

76 Let's denote $\hat{f} = f - f_0$, additional frequency of BTR buses movement that one can spend to eliminate
77 additional vehicles from congested lanes to rise average speed. Using equations (10), (11) and (12) we can
78 express the dependence of average speed ($V = f(\hat{f}, f, k, l)$) as follows: $Ll f k - 108 (0, 0, 0, 86) = e V$ km/h, (10)

79 where, \hat{f} - additional frequency of BTR buses movement that one can spend to eliminate vehicles from
80 regular lanes to rise average speed; l - The number of regular lanes; k - The eliminating coefficient, L - The
81 length of highway, kilometers.

82 The fraction $Ll f k$ reflects the possibility of BRT lane to eliminate additional vehicles from congested lanes
83 and to rise the average speed on regular lanes.

84 Let's see a numeric example.

85 In our case the number of regular lanes equal to 3. As was shown before, f_0 value belongs to a numeric interval
86 (12, 16) and the numeric interval range depends on the average number of passengers of private cars.

87 We suppose that maximum frequency value equal to 30 buses per hour. So, if the average number of passengers
88 of private cars equal to 1, 5 then coefficient $k=67$ and \hat{f} can vary from 0 to (30-16) or inside the interval
89 (0,14).

90 If the average number of passengers of private vehicles equal to 1,1 then coefficient $k=91$ and \hat{f} can vary
91 from 0 to (30-12) or inside the interval (0,18). If values of parameters "l" and "k" are fixed, we can consider V
92 value as a function of \hat{f} with numeric parameters "l" and "k". For $k=67$ and $l=3$ equation (10) is shown as:
93 In case of the articulated bus, if the average number of passengers of private care equal to 1.5 then $k=93$, f_0
94 =12, \hat{f} can range from 0 to 18 buses per hour. The average speed of traffic flow one can estimate as follows:)
95 $3 * 15 f 93 - 108 (0, 0, 0, 86) = e V$ km/h, (13)

96 If the average number of passengers of private care equal to 1.1 then $k=127$, $f_0 = 8$, \hat{f} can range from
97 0 to 22 buses per hour. Average speed of traffic flow can be estimated as follows: We assume that 1) During
98 transportation from suburb to downtown, passengers only boarding buses in suburb area and alighting buses in
99 the downtown area. 2) During rush hours bus passengers load equal to bus capacity. 3) Quality of transfer process
100 is rather high, so buses are not overloaded. Therefore, time for boarding/alighting process during the trip (T_{ba})
101 can be estimated as follows: $\mu = d \text{bus} d \text{bus} ba N C N C T + =$, seconds (15)

102 where: C_{bus} -The capacity of BRT bus; N_d -Numbers of bus doors for boarding/alighting; μ -Boarding
103 rate, second per passenger per door; μ -Accelerating rate, second per passenger per door. Another time spend
104 on accelerating/ decelerating bus (T_{ad}) at each stop. This time can be estimated as follows: $6 * 3 + 6 * 3 =$
105 $1 - (= \max \max d V a N T_{st} ad)$, seconds (16)

106 where: N_{st} -Number of stops on the route; V_{max} -Maximal speed on the route, km/h; a -bus acceleration
107 rate, m/sec²; d -bus deceleration rate, m/sec².

108 The third component of time spend on running along the route with maximum speed (T_{msp}). This time with
109 the same notation one can estimate as follows: Operating speed (V_0) for a line one can estimate as follows:
110 $adba + T T L V + 3600 = , \text{km/h}$

111 Let's estimate the dependence of operating speed on numbers of bus stops on the route in our case for regular
112 and articulated buses.

113 We assume that regular and articulated buses typical dynamic characteristic are: approximately acceleration
114 rate $a=1.6 \text{ m/sec}^2$. Therefore, acceleration time to reach maximum speed 60 km/h $t_a = 10 \text{ seconds}$; deceleration
115 rate $d=1 \text{ m/sec}^2$. Therefore, deceleration time to decelerate from 60 to 0 km/h $d = 16 \text{ seconds}$.

116 Let's calculate length of acceleration/ deceleration way (S). In total $S = 0.5[a(t_a)^2 + a(t_d)^2] = 0.5$
117 $?1.6^2$. We can see, that dependence of operating speed on numbers of bus stops almost identical for regular and
118 articulated buses(see equations (??1) and (??3)).

119 The graph for operating speed for the regular bus (equation 21) is shown in figure 3. The number of stops
120 varies from 2 to 30 . Two stops on the route are terminals only. 30 stops mean two bus stops per kilometer in
121 average. If the number of stops rises then operating speed drops significantly.

122 4 II.

123 5 Conclusion

124 During rush hours travel time from suburb to downtown significantly less than for private vehicles congested in
125 a regular lane. Buses can move along separated BRT lane with maximum speed 60 km/h . The Capacity of BRT
126 bus lane and the operational speed depend on the number of bus stops. The best attraction of BRT lane is buses
127 high speed during rush hours. If the number of stops on the route is not big, then operating speed value is close
128 to maximum speed. Therefore, the number of bus stops of BRT route must be limited to ensure BRT passengers
129 speed advantage over private cars passengers during rush hours.

130 6 Annotation

131 The article deals with public transport. It discusses the possibilities of this transport in solving complex problems
132 that rizrd as a result of uncontrolled motorization. The article focuses on the case study of commuter's movement
133 from suburb to downtown of the city and back along a highway during rush hours when chronic congestions occur.

134 Quantitative estimations of the Bus Rapid Transit efficiency developed and its prospect to eliminate traffic
135 flow congestions discussed. The effects one could reach if (and only if) part of the passengers using private cars
136 will agree to change the mode of transportation and use buses on BRT route. The goal could be reached if
137 the BRT transportation process will be comfortable, buses will not overloaded during rush hours, and operating
138 speed will be much more than the average of dense traffic [7,8].

139 Calculations of the operating speed, travel time, number of BRT buses, needed to eliminate traffic jam,
140 are presented. The calculations made by Fundamental Diagram. Parameters of analytical expressions used were
141 estimated by the author with statistical data, gathered during traffic flow observation on the highways of Moscow
142 and its suburb.

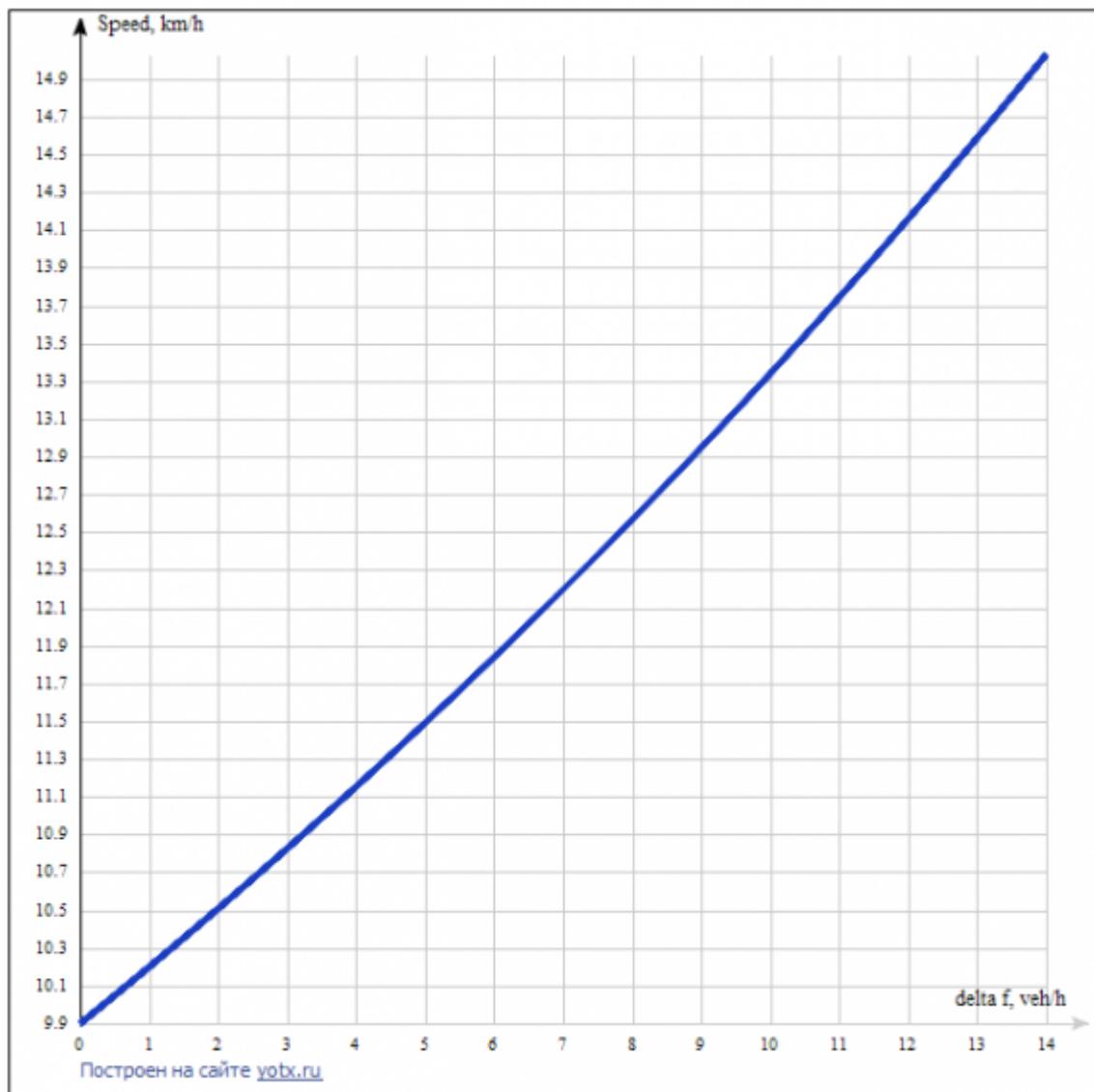


Figure 1:

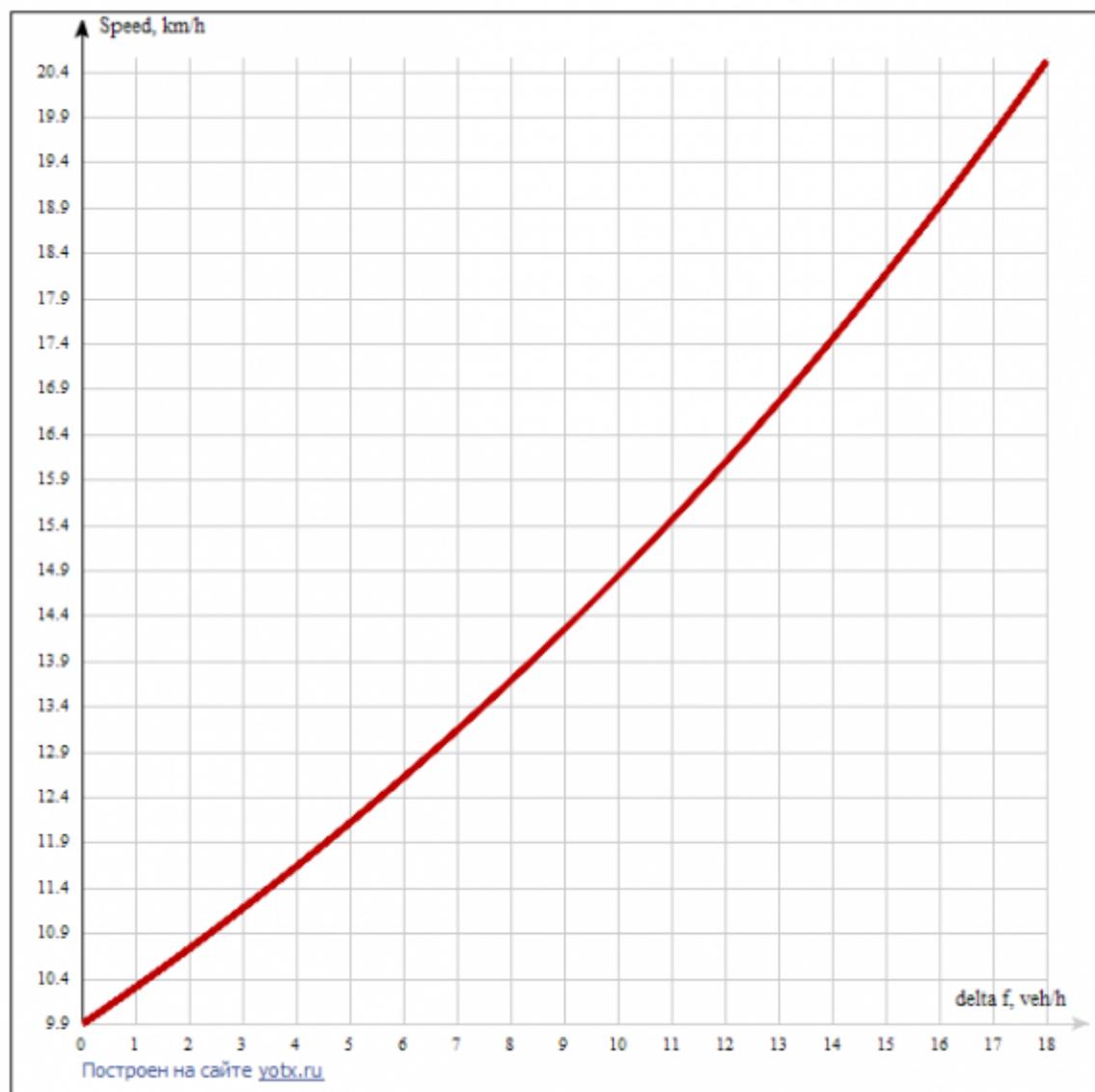


Figure 2:

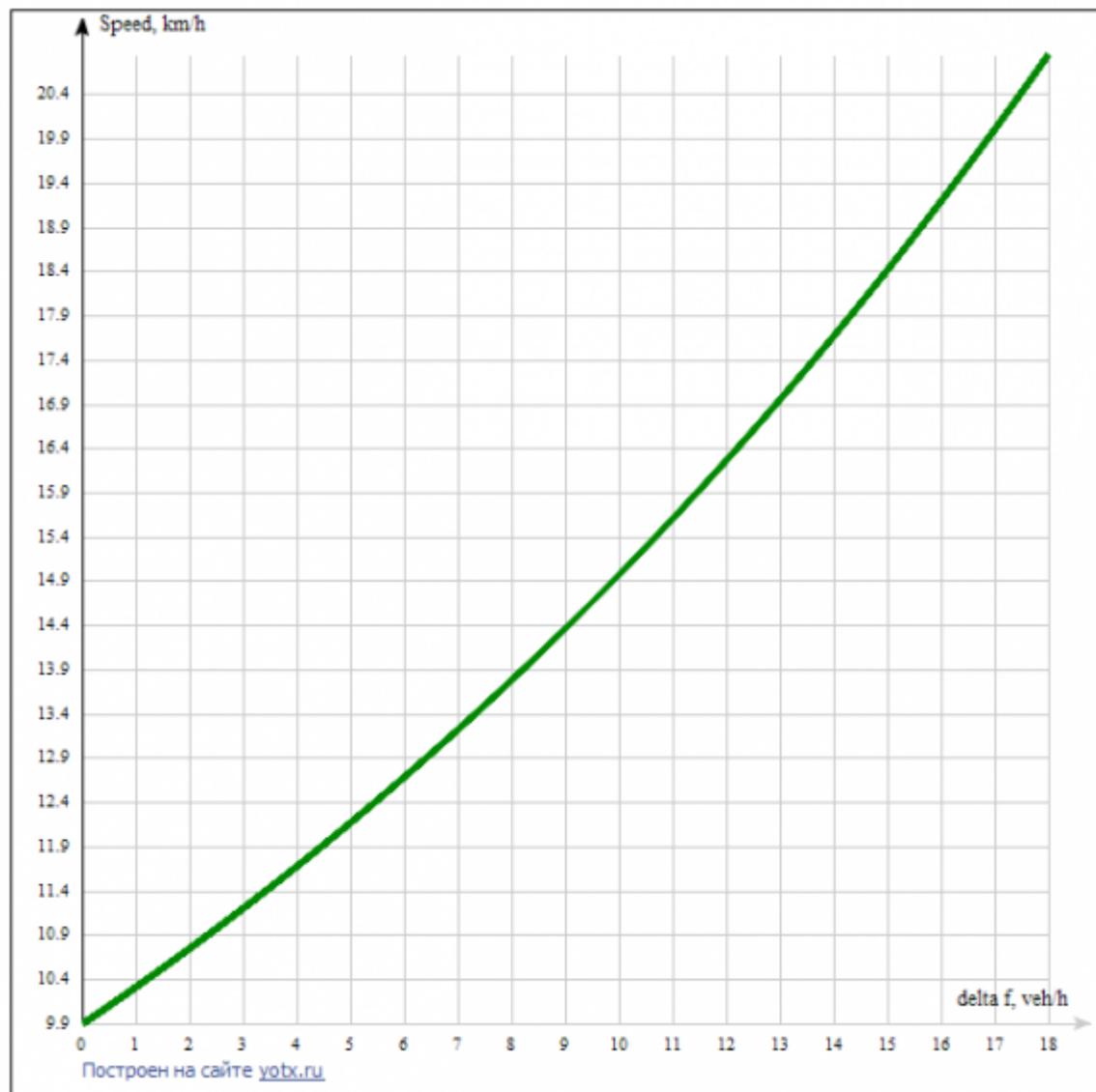
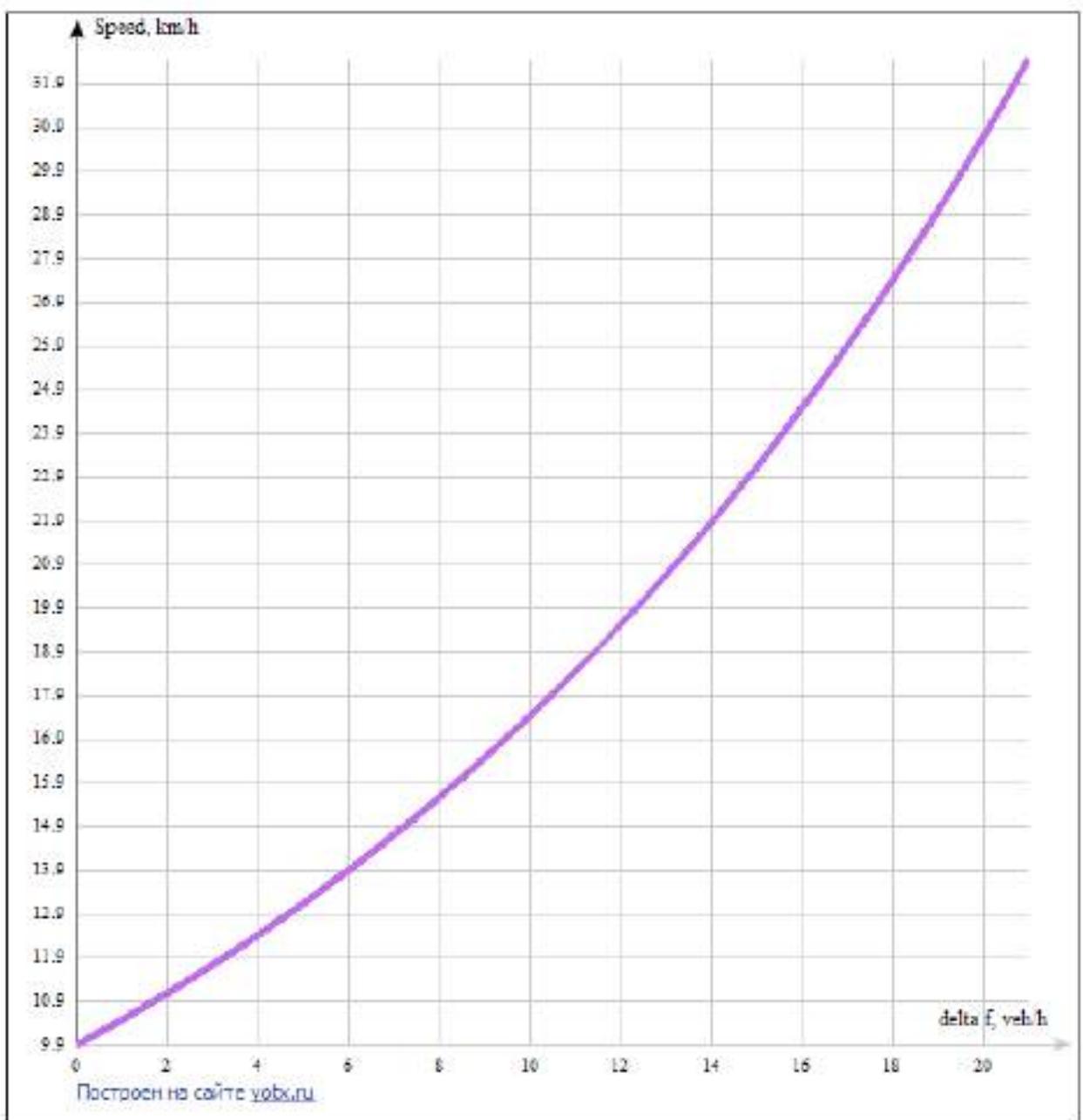


Figure 3:



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Figure 4: 1 Figure 1 : 1 Figure 2 :

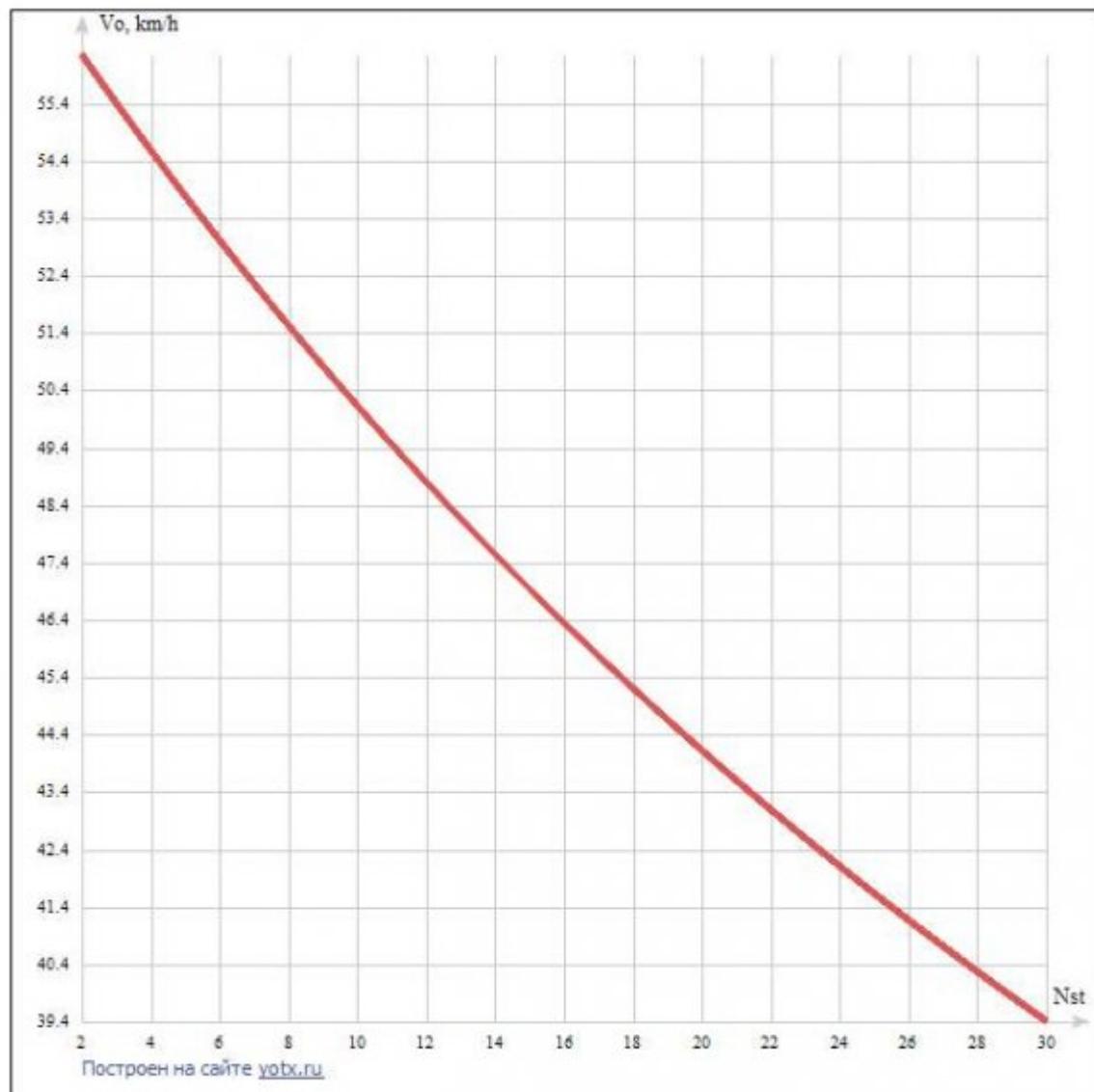


Figure 5:

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