International
Journal
Of Advanced Research in Engineering& Management (IJAREM)
ISSN: 2456-2033 || PP. 53-62

Financing Public Transport Is an Important Dimension of Sustainable Urban Mobility: The Model for Determining the Prices of Passenger Transport Services

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Abstract: This paper describes a model for determining the price of services in public urban transport of passengers. The model allows to include several input parameters related to demand and supply as well as the inclusion of parameters through which the authorities can act in order to improve the mobility of the population. The financing of public urban transport as one of the key dimensions for establishing sustainable urban mobility, using this model, can be maximized. The prices of transport services determined through this model become acceptable in regulating contractual relations between government representatives and operators, and the operators continuously direct them to rationally operate.

Keywords: Prices Transport; Public Transport; Sustainable Urban Mobility; Transport Passenger; Mobility Index

1. Introduction

The trend of settlements in urban areas in the world leads to the conclusion that up to 2025 could live almost 60% of the world population [1].

Not exploiting all the available resources of the urban mobility system leads to the capture of the population from the aspect of ecology, economy, social aspect, traffic and transportation aspects.

In 2014, UITP, along with Arthur D. Little, identified some key dimensions and 25 imperatives that need to be taken into account with regard to mobility in cities wishing to establish sustainable urban mobility.

In estimating the available resources, the realization of the vision of doubling the market share of public transport in the world (PTx2) would have the following effects: saving about 170 million tonnes of oil and 550 million tonnes of CO^2 equivalent; the number of deaths in urban traffic decreased by 15%; doubled the number of jobs in public carriers and reduced the risk of obesity and heart disease by 50% due to the greater role of hiking, cycling and public transport [1].

The establishment of a sustainable urban mobility policy requires cities to develop a political vision and goals of urban mobility based on the strategic alignment of all key public and private actors of the expanded mobility ecosystem. This should inform the visionary urban mobility strategy (priorities and investments to achieve the goals of mobility), which ensures the right balance between enlargement and feasibility.

According to the Mobility Assessment Model [1], the first of a total of 19 criteria is the Financial attractiveness of public transport with a weight of 4 out of a total of 100.

Financial attractiveness of public transport is defined as:

- Ratio between the price of a 5-km journey with private transportation and the price of a 5-km journey with public transport within the agglomeration area
- Private means of transport: car or motorcycle, depending on what type of vehicle dominates in split mode
- Cost of travel with motorized-individual transport: fuel cost only, based on fuel consumption and fuel price including tax; average for gasoline and diesel cost taken
- Cost of public transport: ticket cost for a 5 km distance trip.

Financial attractiveness of public transport (cost of 5 km PT/cost of 5 km) for 11 of 84 cities with the highest rated utilization of sustainable urban mobility varies significantly from 1.7 to 6.7 (Hong Kong 1.7, Stockholm 6.7, Amsterdam 3, Copenhagen 4.8, Vienna 3.9, Singapore 2.6, Paris 2.9, Zurich 3.8, London 3.9, Helsinki 3.6, Munich 4.6) [1].

Due to the pressure on public resources, the transport sector and operators have to specify the cost of transport services more accurately to cover transport costs and increase demand. It should be borne in mind that the cost of the non-cost service carriage will not provide the necessary revenues so that it can be used as such if there are opportunities to generate additional revenue from production services to third parties.
The impact of the overall urban mobility can be significantly improved by defining a pricing model for transport services that will cover all relevant parameters from the aspect of demand and supply of transport.

2. Model for Determining the Price of Tickets in Public Transportation of Passengers

Determination of the prices of services of public urban transport of passengers expressed by tickets in public city transport of passengers is done according to the model which includes determining:
- The price of the transport service (price of the ticket) per number of journeys,
- The price of the transport services for a certain period (the price of the periodic chart) and
- The price of the transport services depending on the length of the relation (price of relational tickets).

The prices determined according to this model are in accordance with the provisions of the Law on Communal Services of Canton Sarajevo.

By using the model, it is possible to determine the price of tickets for all types of tickets, depending on the category of passengers, the area on which the ticket is valid, the number of runs, the time of validity of the ticket and the place of purchase of the ticket.

Tickets showing the prices of transport services can be paper form, magnetic ticket form (magnetic tape ticket), tickets with contact type and contactless type tickets.

The model defines the procedure for its application, as well as the guidelines for controlling the collection of passenger transport services.

The model needs to be adopted by the carrier and the bodies that manage public urban transport in the city, all depending on whether the transport services are communal or commercial.

2.1 Ticket prices per number of journeys and for a certain period of validity

Ticket prices per number of journeys and the prices of periodic tickets are counted for a certain number of areas of validity and depending on the number of runs relevant for determining the prices of tickets, and the basis for their calculation is the triple module. Ticket prices are calculated for certain categories of passengers. The carrier may give a certain discount on the price of the ticket based on the number of journeys and the period of validity. For tickets that additionally burden the carrier for the sale, control of vehicle charging and retention, the carrier may increase the price of tickets through the selective price policy coefficient.

Under the tariff module, the price of a single passenger journey in the first zone is assumed.The prices of the relational tickets are broken depending on the length of the relationship.
The general mathematical model for determining the price of tickets is

$$C_{ijk} = C_0 \cdot N_{ijk} \cdot K_{ijk} \cdot \left(\frac{n+1}{2}\right) \cdot \left(1-\frac{p_{ijk}^{n}}{100}\right) \cdot \left(1-\frac{p_{ijk}^{p}}{100}\right) \cdot \left(1-\frac{p_{ijk}^{kp}}{100}\right) [KM] \quad \text{.........} \quad (1)$$

where is:
C_{ijk} – The price of the ticketof the passenger category *(i)*, (*j*) period of validity, for (*k*) zones
C_0 – Basic Tariff Module *[KM/journey of passenger]* (KM – BAM or EUR or $ ...)
i– Category of user (passengers)
j– The mark of the period for which the ticket is valid
j = 1 ticket valid for 1 hour,
j = 2 ticket valid for 1 day,
j = 3 ticket valid for 10 days,
j = 4 ticket valid for 1 month,
j = 5 ticket valid for 3 months,
j = 6 ticket valid for 6 months,
j = 7 ticket valid for 12 months
j = 0 period is not defined and does not affect the price of the ticket.
k - The number of the zone number for which the ticket is valid:

k = 1 ticket is valid for 1 zone,
k = 2 ticket valid for 2 zones,
k = 3 ticket valid for 3 zones,
k = 4 ticket valid for 4 zones.
n = 1,2,3,4 - the number of zones for which the ticket is valid

$\left(\frac{n+1}{2}\right)$ – Coefficient of degressive growth of medium length in multiple zones (if it is desired to reduce price increase with price increase instead of 2 it can be adopted higher than 2, the same is true, or otherwise if it is desired to increase the increase in price with zone increase instead of 2 it can be adopt less than 2).

N_{ijk} – The number of passenger journeys calculate the price of one ticket (i) passenger category, (j) period of validity, for the (k) zones

K_{ijk} – The selectivity policy coefficient of the ticket price (i) category of passengers, (j) period of validity, for (k) zones($K_{ijk} \geq 1$, 1 and more)

p_{ijk}^{n} $[\%]$ – Discount on the price of the ticket due to the number of journeys on the ticket(i) passenger categories, (j) period of validity, for (k) zones

p_{ijk}^{p} $[\%]$ – Discount on the price of the ticket based on the time period of the vaditity of the ticket and the category of passengers, (j) period of importance, for the (k) zones.

p_{ijk}^{kp} $[\%]$ – Discount on the price of the ticket based on the category of passenger for (i) category of passengers, (j) period of validity, for (k) zones.

The price of the ticket of (i) passenger category, (j) period, can be paid by the traveler for the zone, and for certain passenger catogories, part of the price or the full price can be subsidized by the government from the budget, which is regulated by law, Law on Municipal Utility Activities of the City.
The price of the ticket is equal to the sum of the price paid by the traveler and the part that is being subsidized

$$C_{ijk} = C_{ijk}^{p} + C_{ijk}^{s} \quad [KM] \quad \text{.........} \quad (2)$$

$$C_{ijk}^{p} = C_{ijk} \cdot \left(1 - p_{ijk}^{s}\right) \quad [KM] \quad \text{.........} \quad (3)$$

$$C_{ijk}^{s} = C_{ijk} \cdot p_{ijk}^{s} \quad [KM] \quad \text{.........} \quad (4)$$

where is:

C_{ijk} – The price of the ticketof the passenger category (i), (j) period of validity, for (k) zones

C_{ijk}^{p} – Part of the price of the ticketof the passenger category (i), (j) period of validity, for (k) zones, paid by the user of the service

C_{ijk}^{s} – subsidized part of the ticket price of the passenger category (i), (j) period of validity, for (k) zones

p_{ijk}^{s} $[\%]$ – the percentage of the subsidized part of the ticket price of the passenger category (i), (j) period of validity, for (k) zones.

The tariff module (C_0) is used as a basis for pricing in the public city transport system and is calculated as the product of unit costs and the average length of the passenger journey in the first zone

$$C_0 = T \cdot l_{srv} \quad [KM] \quad \text{.........} \quad (5)$$

where is:

- T $\left[\frac{KM}{putnik \cdot km}\right]$ – unit cost of transporting one passenger per kilometer of the observed area or line without VAT, and calculated according to the expression

$$T = \frac{T_v}{m \cdot \frac{p_v}{100}} \quad \left[\frac{KM}{passenger \cdot km}\right] \quad \text{.........} \quad (6)$$

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Of Advanced Research in Engineering& Management (IJAREM)
ISSN: 2456-2033 || PP. 53-62

The unit cost of transporting one passenger per kilometer of the observed area or lines includes the costs of: fuels, electrical energy, oils, lubricants, tires, maintenance and repair, cooling fluids, insurance, registration, transport management, development and information support for the management, tickets, wage costs and hot meals of employees, and other costs necessary for the realization of the transport process.

- $T_v \left[\frac{KM}{vehicle \cdot km}\right]$ - unit cost per vehicle per kilometer of the observed area or line
- *m[places = seating places + standing places]* - number of places in the vehicle
- p_v *[%]* – The percentage of average vehicle occupancy throughout the day
- l_{srv} *[km]* – Mean length of one passenger's journey in one zone - reference zone.

2.2 Input parameters for calculating ticket prices

Data for the determined price of tickets can be presented in tabular form (Table 1).

Table 1View the data to calculate the prices of tickets

The ticket name specified with (i,j,k)	T [KM/pkm]	l_{srv} [km]	N_{ijk}	K_{ijk}	k [zona]	j	Discount carrier			Price without VAT	Price with VAT	p^s_{ijk} [%]	Part of the price paid by the user	Subsidized part of the price
							p^n_{ijk} [%]	p^p_{ijk} [%]	p^{kp}_{ijk} [%]	C_{ijk} [KM]	$1,17 \cdot C_{ijk}$ [KM]		C^p_{ijk} [KM]	C^s_{ijk} [KM]
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ticket 1														
Ticket 2														
Ticket 3														
…														

The meaning of the mark is described in Section 2.1.

2.3The price of the transport services depending on the length of the relation (price of relational tickets)

The price of the relational ticket is determined by the number of segments on the line for which the ticket is issued. The boundaries of each line segment should be defined so as to coincide with the boundaries of the zone of the tariff system. In this case, the price of individual tickets is determined by the expression (1).

If the system system principles are not used, it is necessary to define a scalar with the boundaries from which the number of miles is the constant cost of one journey. In this way it is possible to determine the cost of journey between all the points on one line and present in the form of a matrix.

When determining the price matrix, a condition is required

$$\sum_{j=m+1}^{k} l_{mj} \le l_c \le \sum_{j=m+1}^{k+1} l_{mj}$$, for specific*m*

whereis:

k - The standpoint that we are considering, ie, determines its merging into a particular segment

m - The position marked as the previous breakpoint.

Relational tickets are one-way tickets and their price depends on the distance between the point where the traveler entered and the point of exit from the vehicle.

Ticket prices on the line are determined based on the price of transport for the length of the relation given in the table (Table 2).

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Table 2 Prices of transport services depending on the length of the relation - scalar

Limits of distance between stops	Price KM
1	*2*
tol_1 km	c_1
froml_1 to l_2 km	c_2
froml_2 to l_3 km	c_3
...	...
froml_{i-1} to l_i km	c_i
...	...

For the distance between two stops [km] on the line (Table 3) that is within the limits given in the table (Table 2, column 1), the transport service price is read from the table (Table 2, column 2) and entered in the appropriate field in the table (Table 4).

Table 3 Distance on the line - the remote

Name of line

l_i *[m]*

0	S_1	Stops				
l_1	l_1-*0*	S_2				
l_2	l_2-*0*	$l_2 - l_1$	S_3			
...	...	...	...	...	S_{i-1}	
l_i	l_i -*0*	$l_i - l_2$	$l_i - l_3$	...	$l_i - l_{i-1}$	S_i
...	...	...	...	...	...	...

Table 4 Ticket prices on the line

Name of line

l_i *[m]*

0	S_1	Stops				
l_1	c_{12}	S_2				
l_2	c_{13}	c_{23}	S_3			
...	...	...	...	...	S_{i-1}	
l_i	c_{1i}	c_{2i}	c_{3i}	...	c_{i-1i}	S_i
...	...	...	...	...	...	...

3. Application of the Model for Determining the Price of the Service of Transport of Passengers

The application of the described model was carried out on the concrete case of determining the proposal of the prices of passenger transport services in the city of Sarajevo, the capital of Bosnia and Herzegovina.

The price proposal was prepared by the expert service of the operator Public utility company"KJKP GRAS", which carries out transportation with 4 systems: tram, trolleybus, bus and minibus.

According to the tags used in themodel in the ticket structure are marked with indexes having the following meaning:

i - category of users (passengers)
i = 1 adult
i = 2 preschool children
i = 3 employees
i = 4 unemployed
i = 5 retired
i = 6 elderly persons without the right to a pension
i = 7 student elementary school

i = 8 pupil high school
i = 9 student - regular
i = 10 persons with congestion
i = 11 of the Express Line Service
i = 20 passengers caught without a ticket.

j - the period for which the card is valid (1 - 1 hour, 2 - 1 day, 3 - 10 days, 4 - 1 month, 5 - 3 months, 6 - 6 months, 7 - 1 year, 0 - period is not relevant for the price tickets)

k - type of tisket in relation to the number of zone of validity, *k* = *n* (1 zone, 2 zones, 3 zones, 4 zones)

n - number of zones for which the price of tickets is calculated (n = 1,2,3,4)

N_{ijk}- number of journeys for which ticket is valid (*i*-th passenger category, *j*-th period, *k*-zone of validity)

Z_{ijk} - the price of the ticket of the i-th passenger category for a certain period of the zone (example: *C1,8,4* - the price of a ticket for one adult journey for 4 zones)

In the tables (

Table 5,

Table 6), the values of the input parameters for determining the price of tickets are given.

Table 5Input parameters for determining price of tickets are constant for all types of tickets

Parameter name	Parameter tag	Value	Unit of measure
1. The unit cost of one passenger per kilometer of the observed area or line	T	*0,18*	*[KM/pass.-km]*
2. Average length of one passenger's journey in one zone - reference zone	l_{srv}	*3,15*	*[km]*

The tariff module is unique for all types of cards and amounts

$$C_0 = T \cdot l_{srv} = 0{,}18 \cdot 3{,}15 = 0{,}567 \ [KM]$$

The discount on the number of months of the ticket's validity was determined according to the recommended coefficient k_p

Table 6Recommended discount on the number of months of the ticket's validity

Coefficient k_p	Number of months of the ticket's validity N_{mj}	Discount $p^{p}_{ijk} = k_p \cdot N_{mj}$ [%]
1,5	*1*	*1,50*
1,5	*3*	*4,50*
1,5	*6*	*9,00*
1,5	*12*	*18,00*

Ticket prices for a number of areas of importance in Canton Sarajevo are based on the principles of the zone tariff system with 4 zones markedwith A, B, C and D, (Figure 1).

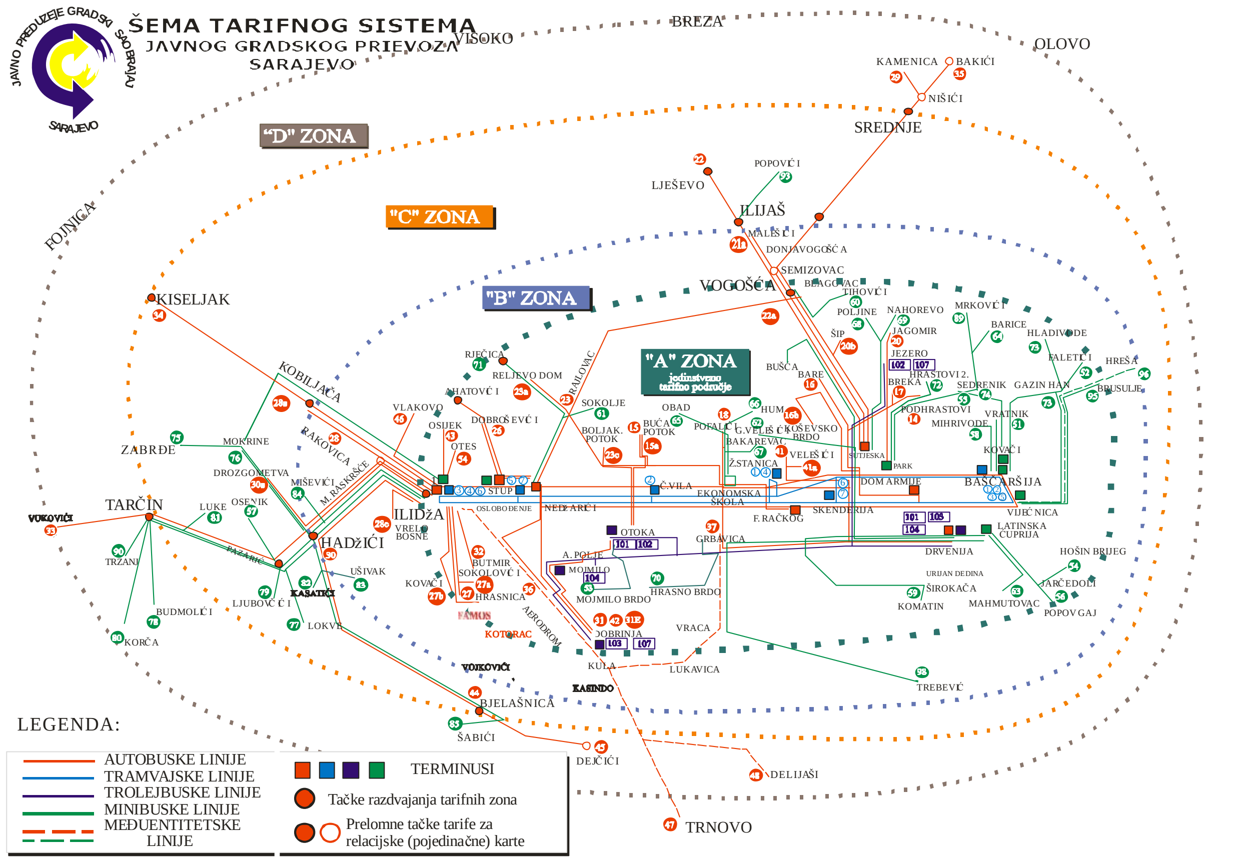

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Figure 1 Boundaries of the Tariff System Zone in Canton Sarajevo

A ticket valid for a single zone is issued for A - zone, B - zone, C - zone or D - zone.
A ticket valid for two zones is issued for A+B - zone, B + C - zone or C + D - zone.
A ticket valid for three zones is issued for A+B+C - zone or, B + C + D - zone.
A ticket valid for four zones is issued for A+B+C+D zone, valid for all zones.

The table (Table 7) gives the prices of tickets calculated according to the Model of the Tariff System of Canton Sarajevo - MTS-KS and adopted input data.

Table7Prices of individual and periodical tickets (part table) (*1 EUR = 1.95 KM; VAT 17%*)

	The ticket name sticketpecified with (*i,j,k*)	Ticket prices without discounts *[KM]*		Discount on the price of tickets with VAT *[KM]*			Discount pric for a validity period with discounts on the number o journeys and category of passengers *[KM]* VATinclud	Price of tickets with included discounts *[KM]*	
		No VAT included C_{ijk}	VAT include d C_{ijk}	*on the number of journeys*	*on a period of validate*	*or the category o passengers*		No VAT include d C_{ijk}	VAT included $C_{ijk}{\cdot}0{,}17$
1	*2*	*3*	*4*	*5*	*6*	*7*	*8 (4-5-7)*	*9 (4-5-6-7)*	*10 (9·0,17)*
	TICKETS ON NUMBER OF JOURNEYS								
A	**Individual tickets**								
1.	Ticket with 1 adult journey	1,71	2,00	0,00	0,00	0,00	2,00	1,71	2,00
2.	Map with 1 children's ride	1,71	2,00	0,00	0,00	1,00	1,00	0,85	1,00

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ISSN: 2456-2033 || PP. 53-62

The ticket name sticketpecified with (*i*,*j*,*k*)		Ticket prices without discounts *[KM]*		Discount on the price of tickets with VAT *[KM]*			Discount pric for a validity period with discounts on the number o journeys and category of passengers *[KM]* VATinclud	Price of tickets with included discounts *[KM]*	
		No VAT included Ci_{jk}	VAT include d C_{ijk}	*on the number of journeys*	*on a period of validate*	*or the category o passengers*		No VAT include d Ci_{jk}	VAT included $Ci_{jk}\cdot 0,17$
1	2	3	4	5	6	7	8 (4-5-7)	9 (4-5-6-7)	10 (9·0,17)
3.	A ticket with 1 journey by a tram and trolley bus driver	2,14	2,50	0,00	0,00	0,00	2,50	2,14	2,50
4.	Children's ticket for 1 journey by a tram and trolley bus driver	2,14	2,50	0,00	0,00	1,25	1,30	1,11	1,30
5.	Express Line Ticket	2,56	3,00	0,00	0,00	0,00	3,00	2,56	3,00
6.	Night driving ticket for 1 zone	3,01	3,52	0,00	0,00	0,00	3,50	2,99	3,50
7.	Night driving ticket for 2 zones	4,51	5,27	0,00	0,00	0,00	5,30	4,53	5,30
8.	Night Trip Ticket for 3 zones	6,01	7,03	0,00	0,00	0,00	7,00	5,98	7,00
9.	Ticket for night driving for 4 zones	7,51	8,79	0,00	0,00	0,00	8,80	7,52	8,80
10	Additional charge	25,66	30,02	0,00	0,00	0,00	30,00	25,64	30,00
B	**Ticket with more journeys**								
11	Two-way ticket - magnetic	3,42	4,01	0,20	0,00	0,00	3,80	3,25	3,80
12	5-way ticket - magnetic	8,56	10,02	1,00	0,00	0,00	9,00	7,69	9,00
13	10-magnetic ticket - magnetic	17,12	20,03	3,01	0,00	0,00	17,00	14,53	17,00
14	Return ticket - magnetic	3,42	4,01	0,40	0,00	0,00	3,60	3,08	3,60
15	Child Return Ticket - Magnetic	3,42	4,01	0,40	0,00	2,00	1,60	1,37	1,60
	TICKETS FOR A PERIOD (PERIODIC)								
C	**Ticket for hour/day**								
16	Ticket for 1 hour - magnetic	3,06	3,58	0,18	0,36	0,00	3,40	2,56	3,00
17	Ticket for 1 day	8,51	9,95	1,00	1,49	0,00	9,00	6,41	7,50
18	Ticket for 10 days	56,70	66,34	9,95	13,27	0,00	56,40	36,84	43,10
D	**Tickets issued in the name of the user**								
D1	***Monthly tickets***								
19	Ticket for 1 zone	45,36	53,07	0,00	0,66	0,00	53,10	44,79	52,40
20	Ticket for 2 zones	62,09	72,64	0,00	0,91	0,00	72,60	61,28	71,70
21	Ticket for 3 zones	74,84	87,57	0,00	1,09	0,00	87,60	73,93	86,50
	...								

Calculation of the price of tickets on the line was made based on the input data of the scales and remote sensors for each line.

Table 8Scale - prices of transport services depending on the length of the relation

Distance between stops	Price KM
to 6 km	2
6,01 to 12 km	3
12,01 to 18 km	4
18,01 to 24 km	5
24,01 to 36 km	6
36,01 to 55 km	7

Below is a price list for one line, Sutjeska - Kamenica

Sutjeska-Krivojevići

Stops	Distance [km]							
Sutjeska	0,0	Sutjeska						
Vogošća	11,0	3,00	Vogošća					
Semizovac	15,0	4,00	2,00	Semizovac				
Gora	22,0	5,00	3,00	3,00	Gora			
Srednje	31,0	6,00	5,00	4,00	3,00	Srednje		
Nišići	38,0	7,00	6,00	5,00	4,00	3,00	Nišići	
Krivojevići	39,0	7,00	6,00	3,00	4,00	3,00	2,00	Krivojevići

4. Conclusion

The presented model for determining the prices of passenger transport services by public city transport enables precise determination of the price of tickets for the input parameters, regardless of whether they are on the side of the demand or supply.

By applying this model, overall mobility performance in urban areas can be significantly improved as it is possible to analyze the impact of individual input sizes on the transport cost. Each category of transport service users has elasticity of demand, so it is possible to rationalize discounts and subsidies in order to achieve acceptable mobility of the population.

Authorities in the city manage more effectively the trends that are more favorable from the aspect of ecology, environmental impacts, impunity, and traffic congestion on the network of roads.

Particular emphasis should be placed on the applicability of the model described in the definition of contractual relations between the authorities and the operator.

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