GINI INDEX AS A MEASURE OF PASSENGER TRAFFIC CONCENTRATION ON THE BUCHAREST SUBWAY

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Abstract: The mobility of residents is one of the necessary conditions for ensuring a functional urban area. The higher the mobility of residents and the easier accessibility to points of interest, the higher the quality of life. Public transport service has been promoted to reduce traffic congestion problems and environmental impact caused by car dependence. Several modes of public transport are available in the Bucharest Metropolitan Area, such as buses, minibuses, taxis, trains, trams and metro. The metro can greatly improve the city's ground traffic congestion and urban traffic environment, making people's travel more convenient. Accurate analysis and prediction of metro passenger flow has always been one of the key tasks of urban rail transit management departments. Especially in the context of the rapid growth of rail transit capacity and changing passenger needs, the need for passenger flow analysis is even more significant. This article complements the analysis of Bucharest metro passenger flow by analyzing big data. It is of great importance to solve urban congestion, optimize the traffic network and protect public transport.

Keywords: Public passenger transport, mobility, accessibility.

1. INTRODUCTION

According to Order No. 972 of October 3, 2007 for the approval of the Framework Regulation for the provision of local public transport and the Framework Specifications for local public transport services, the organization and performance of specific activities of local public transport services must ensure the satisfaction of public utility requirements and needs of local communities, namely [1]:

- priority satisfaction of the transport needs of the population and economic operators on the territory of the administrative-territorial units;
- improvement of road safety, environmental protection and the quality of local public transport;
- safe and comfortable travel, including through risk insurance of transported

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goods and persons, as well as their belongings through insurance policies;
- equal and non-discriminatory access of transport operators, respectively authorized carriers, to the local public transport market;
- optimization of the functioning of the local public transport market by ensuring a normal, dynamic and fair competitive framework.

The role of transport is to provide people with access to opportunities so that they can engage in activities such as jobs, education and health. Public transport, in particular, should commit to this mission while being inclusive, accessible and safe. If transport planners fail to achieve this goal, increasing inequality may further exacerbate a social justice problem [2, 3, 4].

The aim of this study is to use the Gini coefficient, widely used in the social sciences, as an index to assess the concentration of passenger traffic on the Bucharest metro. Its main purpose as a method in transport is to measure the concentration of traffic, mainly at terminals. In public transport systems, such as buses, trains and metro, more extensive operations can lead to lower costs per passenger through factors such as shared infrastructure and increased efficiency. However, there are limits, and at very high levels of demand, congestion and overcrowding can lead to costs that increase with decreasing service quality. Temporal variations in the Gini coefficient reflect changes in the comparative advantages of a location within the transport system. The paper proposes the Gini index as a measure of demand imbalances in public transport [4, 5, 6, 7].

2. DESCRIPTIVE PERSPECTIVES

2.1. Quality indicators of public transport service quality

The operation of the local public transport service must ensure [1]:
- increasing the level of service quality and comfort of users of public local public transport services through regular routes;
- access to local public transport services and protection of disadvantaged social categories;
- informing the traveling public;
- performing local public transport of people through regular routes under conditions of regularity, safety and comfort;
- correlating transport capacity with existing passenger flows;
- continuity of local public transport service through regular routes.

There is a wide variety of indicators that characterize the quality of public transport services. These indicators can be introduced into different categories, such as [8, 9, 10, 11, 12]:
- accessibility – indicators that assess the accessibility of a potential passenger to a public transport service, for different types of trips;
- service monitoring – indicators that assess the experiences of passengers who use public transport services on a daily basis;
- journey time – indicators that measure the duration of a journey in the public

transport system and compare it to the durations achieved with other modes of transport or with an ideal value;
- safety and security – indicators that assess the probability that a passenger will be involved in an accident or become a victim while using a public transport service;
- reliability – indicators of the effectiveness of the operator's programme and its ability to meet the commitments assumed through the publicly available programmes;
- economic characteristics – economic indicators of the performance of public transport services;
- capacity – the ability of operators to fully satisfy the demands placed on the public transport system in different areas and at different times.

2.2. Bucharest Subway

The Bucharest Subway is the underground transportation system in the Romanian capital, inaugurated on November 16, 1979. [13]. By Government Decision no. 482 of June 17, 1999, the Autonomous Metro Operating Company becomes the Bucharest Metro Transport Commercial Company "Metrorex" - S.A. [14]. The network characteristics are (Figure 1) [15]:
- Metro lines: 5;
- Network length: 77,77 km double track;
- Total number of km (km deployed): 189,367;
- Number of depots: 6;
- Number of stations: 64;
- Number of station entrances: 193;
- Average distance between two stations: 1,177 km;
- Length of a station: 135-175 m;
- Deepest station: Piața Unirii 2 - 20 m;
- Average depth of a station: 12 m;
- Largest interstation: A. Vlaicu - Aviatorilor – 1,973 km;
- Gauge: 1432 mm;
- Number of escalators: 180;
- Number of elevators: 153;
- Number of platforms for people with reduced mobility: 4;
- Number of CCTV cameras: over 1800;
- Number of fire and burglary detectors: over 6400.

The fleet of electric and mechanical trains (Figure 2) in operation is represented by:
- 44 Bombardier MOVIA type trains;
- 15 IVA Astra type trains;
- 23 CAF trains.

Fig. 1. Map of the subway network in Bucharest [16]

Fig. 2. Metrorex trains: Bombardier; CAF; IVA (from left to right) [17]

2.3. Gini index in the context of travel demand

The Gini coefficient measures the statistical dispersion within two frequency distributions. In the context of public transport, we intend to measure the dispersion of demand along a sequence of jointly served line sections, taking into account that longer sections have a higher share in both operational and user costs. We adopt the concept of the Gini coefficient as a measure of demand inequality by plotting the cumulative share of demand at the section level in increasing order of the cumulative length of the sections. The resulting function is called the Lorenz curve [6]. A stylized example is graphically represented in Figure 3.

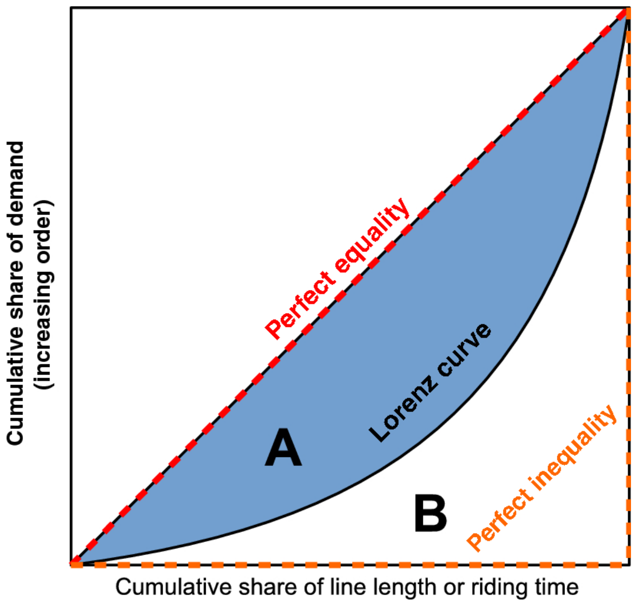

Fig. 3. Definition of the Gini coefficient in the transport demand context [6]

The Lorenz curve is the diagonal of the graph in the case of perfect equality, that is, when both the number of passengers and all costs are distributed uniformly along the line. At the other extreme, if all demand is concentrated on a negligibly short section of line, then the Lorenz curve remains flat in its initial part, then rises very rapidly when we finally consider the only congested section of the line. Thus, the curve moves along both sides of the graph, representing perfect inequality [6]. The Gini coefficient is defined, graphically, as the ratio between two areas comprising the sum of all deviations between the Lorenz curve and the line of perfect equality (A) divided by the difference between the line of perfect equality and the line of perfect inequality (A+B) [6, 18]:

$$A + BG = \frac{A}{A + B} = 2AA + B = 0{,}5 \tag{1}$$

The resulting Gini index is 0 in the case of perfect equality and 1 in the case of perfect inequality.

3. ANALYSIS OF PASSENGER TRAFFIC CONCENTRATION

To illustrate the functionality of the Gini coefficient, the degree of concentration of passenger traffic on the Bucharest metro, by lines and stations, was examined. Figure 4 shows the variation in the total number of passengers during the period 2005-2024, and Figure 5 shows the variation in the number of passengers on the 5 lines, M1, M2, M3, M4 and M5 during the period 2018-2024. [15, 19, 20, 21, 22, 23, 24, 25, 26, 27]

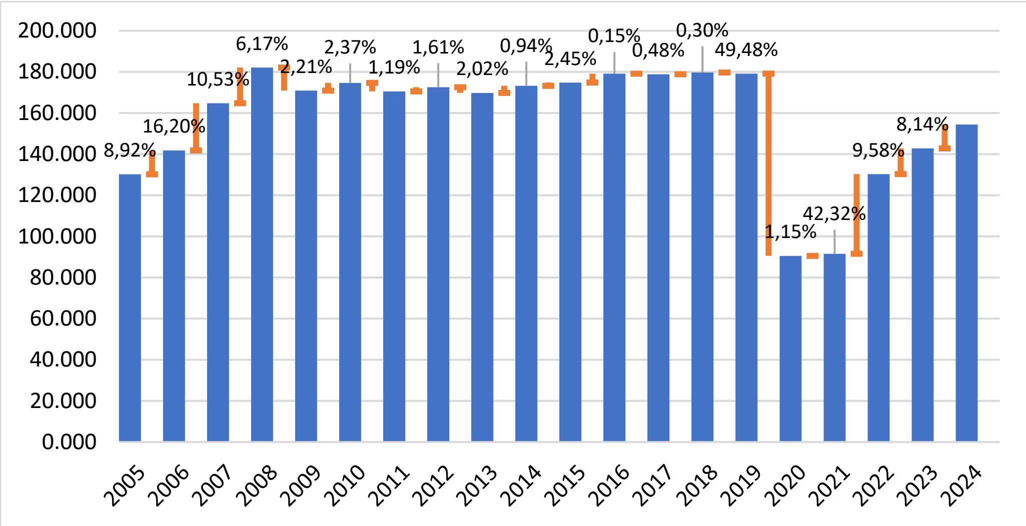

Fig. 4. Total number of passengers on the Bucharest metro between 2005-2024

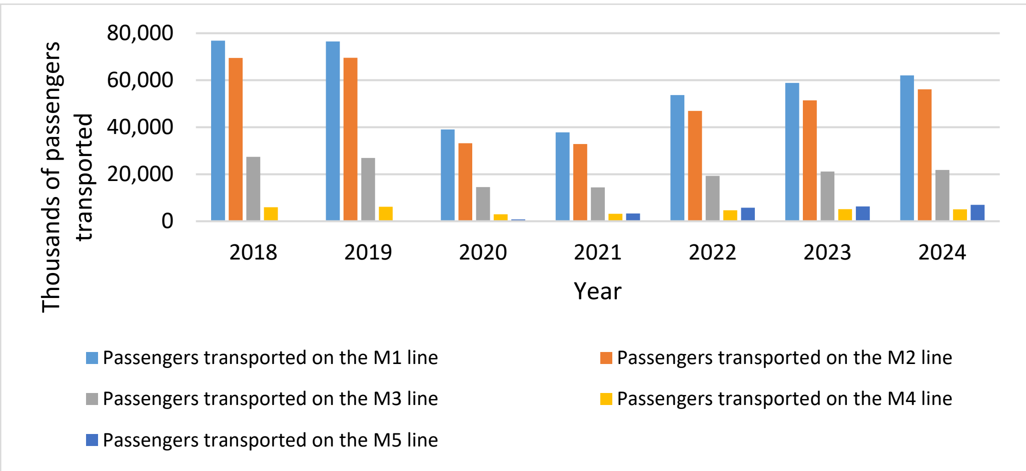

Fig. 5. Number of passengers on lines, period 2018-2024

4.1. Index of Difference (ID)

The sum of the vertical deviations between the Lorenz curve and the line of perfect equality, also known as the sum of the Lorenz differences. The closest *ID* is 1 (or 100% instead of fractions), the most different of the distribution is at the line of perfect equality.

$$ID = 0{,}5 \sum_{i=1}^{N} |X_i - Y_i| \tag{2}$$

where: X and Y - percentages (or fractions) of the total number of elements and their values, respectively (the most common being traffic); N - number of elements.

4.2. Gini coefficient

The Gini coefficient represents the area of concentration between the Lorenz curve and the line of perfect equality and is presented as a proportion of the area contained in the triangle defined by the line of perfect equality and the line of perfect inequality.

The closest is 1, the most uneven distribution is:

$$G = 1 - \sum_{i=0}^{N} (\sigma Y_{i-1} + \sigma Y_i) \cdot (\sigma X_{i-1} - \sigma X_i) \tag{3}$$

where: σX and σY - cumulative percentages of X_s and Y_s (in fractions); N - number of elements.

The analysis was then carried out in 2019, the year before the pandemic, as 2019 had the highest number of passengers transported even though only lines M1-M4 were in operation (Tables 1-4, Figures 6-9). It should be noted that it is possible for a passenger to initiate a trip in a metro station and yet not travel by metro through that station.

Concrete example: A passenger initiates a trip in the Piața Unirii 1 metro station, passes through the Piața Unirii 1 - Piața Unirii 2 connecting passage and then boards the metro train at the Piața Unirii 2 station, in the direction of Pipera or Berceni. In this case, the trip made on line M2 appears in the list related to the Piața Unirii 1 station (the station where the trip was initiated).

Piața Unirii 1 station with a traffic of 10,481,259 passengers accounts for 0.0476 or (4.76%; *X*) of all terminals or 0.137 (13.7%; *Y*) of all traffic. The difference index of this distribution is 0.193 (0.387 × 0.5) (Table 1, Figure 6), and indicates the average level of concentration.

Table 1. *Calculation of the Gini coefficient for line M1*

Stations	*Number of passengers*	*X*	*Y*	*|X-Y|*	*σX*	*σY*	*σX$_{i-1}$ – σX$_i$, (B)*	*σY$_{i-1}$ + σY$_i$, (A)*	*A×B*
Piața Unirii 1	10.481.259	0,0476	0,137	0,089	0,0476	0,137	0,0476	0,137	0,007
Obor	6.116.815	0,0476	0,080	0,032	0,0952	0,217	0,0476	0,354	0,017
Piața Victoriei 2	5.860.749	0,0476	0,077	0,029	0,1429	0,294	0,0476	0,510	0,024
Crângași	5.621.475	0,0476	0,073	0,026	0,1905	0,367	0,0476	0,661	0,031
Gara de Nord	4.331.078	0,0476	0,057	0,009	0,2381	0,424	0,0476	0,791	0,038
Dristor 2	3.968.085	0,0476	0,052	0,004	0,2857	0,475	0,0476	0,899	0,043
Ștefan cel Mare	3.912.739	0,0476	0,051	0,004	0,3333	0,527	0,0476	1,002	0,048
Piața Iancului	3.501.172	0,0476	0,046	0,002	0,3810	0,572	0,0476	1,099	0,052
Timpuri Noi	3.372.543	0,0476	0,044	0,004	0,4286	0,616	0,0476	1,189	0,057
Nicolae Grigorescu	3.230.786	0,0476	0,042	0,005	0,4762	0,659	0,0476	1,275	0,061
Titan	3.217.328	0,0476	0,042	0,006	0,5238	0,701	0,0476	1,359	0,065
Eroilor	3.151.677	0,0476	0,041	0,006	0,5714	0,742	0,0476	1,443	0,069
Piața Muncii	3.057.634	0,0476	0,040	0,008	0,6190	0,782	0,0476	1,524	0,073
Grozăvești	3.020.375	0,0476	0,039	0,008	0,6667	0,821	0,0476	1,603	0,076
Costin Georgian	2.715.071	0,0476	0,035	0,012	0,7143	0,857	0,0476	1,678	0,080
Republica	2.330.836	0,0476	0,030	0,017	0,7619	0,887	0,0476	1,744	0,083
Izvor	2.303.562	0,0476	0,030	0,018	0,8095	0,917	0,0476	1,805	0,086
Basarab	2.094.814	0,0476	0,027	0,020	0,8571	0,945	0,0476	1,862	0,089
Petrache Poenaru	1.801.330	0,0476	0,024	0,024	0,9048	0,968	0,0476	1,913	0,091
Mihai Bravu	1.761.814	0,0476	0,023	0,025	0,9524	0,991	0,0476	1,960	0,093
Pantelimon	663.857	0,0476	0,009	0,039	1,0000	1,000	0,0476	1,991	0,095
Total M1	76.515.000	1,000	1,000	0,387	–	–	–	–	1,276

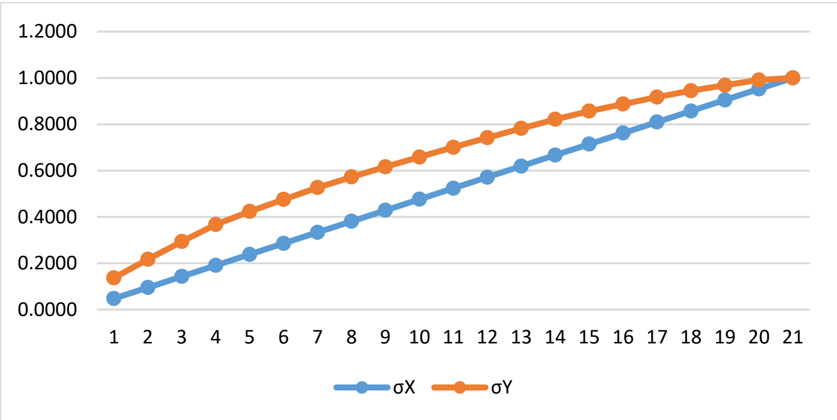

Fig. 6. Lorenz curve for the M1 line

Table 2. *Calculation of the Gini coefficient for line M2*

Stations	**Number of passengers**	*X*	*Y*	*|X-Y|*	**σ*X***	**σ*Y***	**σ*X$_{i-1}$* – σ*X$_i$*, (*B*)**	**σ*Y$_{i-1}$* + σ*Y$_i$*, (*A*)**	*A×B*
Aurel Vlaicu	8.124.671	0,0667	0,117	0,050	0,0667	0,117	0,0667	0,117	0,008
Piața Sudului	6.930.339	0,0667	0,100	0,033	0,133	0,217	0,0667	0,333	0,022
Universitate	6.507.055	0,0667	0,094	0,027	0,200	0,310	0,0667	0,527	0,035
Pipera	6.433.783	0,0667	0,093	0,026	0,267	0,403	0,0667	0,713	0,048

Stations	**Number of passengers**	***X***	***Y***	***|X-Y|***	**σ*X***	**σ*Y***	**$\sigma X_{i-1} - \sigma X_i$, (*B*)**	**$\sigma Y_{i-1} + \sigma Y_i$, (*A*)**	***A*×*B***
Piața Unirii 2 M1+M3	6.346.017	0,0667	0,091	0,025	0,333	0,494	0,0667	0,091	0,006
Piața Romană	6.115.023	0,0667	0,088	0,021	0,400	0,582	0,0667	1,076	0,072
Eroii Revoluției	5.198.004	0,0667	0,075	0,008	0,467	0,657	0,0667	1,238	0,083
Aviatorilor	4.784.815	0,0667	0,069	0,002	0,533	0,725	0,0667	1,382	0,092
Apărătorii Patriei	4.211.462	0,0667	0,061	0,006	0,600	0,786	0,0667	1,511	0,101
Dimitrie Leonida	4.169.524	0,0667	0,060	0,007	0,667	0,846	0,0667	1,632	0,109
Constantin Brâncoveanu	3.871.741	0,0667	0,056	0,011	0,733	0,902	0,0667	1,748	0,117
Piața Victoriei M1	3.548.468	0,0667	0,051	0,016	0,800	0,953	0,0667	1,854	0,124
Tineretului	2.750.835	0,0667	0,040	0,027	0,867	0,992	0,0667	1,945	0,130
Berceni	538.263	0,0667	0,008	0,059	0,933	1,000	0,0667	1,992	0,133
Tudor Arghezi	0	0,0667	0,000	0,067	1,000	1,000	0,0667	2,000	0,133
Total M2	69.530.000	1,000	1,000	0,384	–	–	–	–	1,077

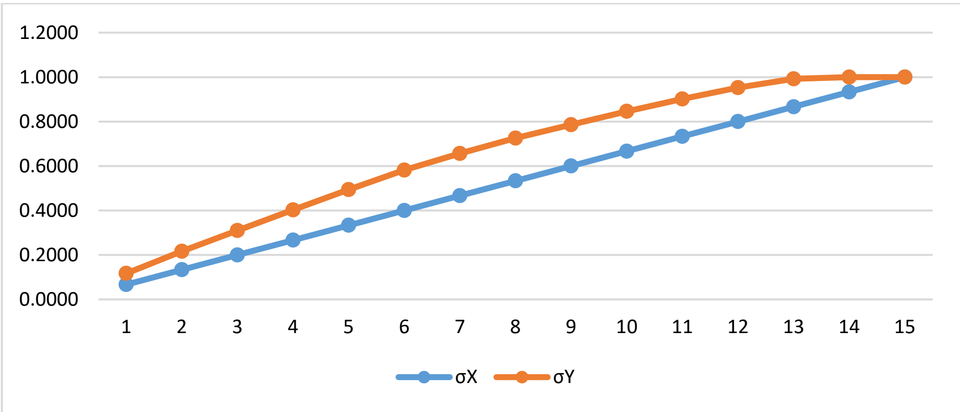

Fig. 7. Lorenz curve for the M2 line

Aurel Vlaicu station with a traffic of 8,124,671 passengers for 0.0667 or (6.67%; *X*) of all terminals or 0.117 (11.7%; *Y*) of all traffic. The difference index of this distribution is 0.193 (0.384 × 0.5) (Table 2, Figure 7), and indicates the average level of concentration.

Lujerului station with a traffic of 5,090,341 passengers for 0.067 or (6.7%; *X*) of all terminals or 0.189 (18.9%; *Y*) of all traffic. The difference index of this distribution is 0.506 (1.013 × 0.5) (Table 3, Figure 8), and indicates the average level of concentration.

1 Mai station with a traffic of 1,631,501 passengers for 0.125 or (12.5%; *X*) of all terminals or 0.264 (26.4%; *Y*) of all traffic. The difference index of this distribution is 0.166 (0.332 × 0.5) (Table 4, Figure 9), and indicates the average level of concentration.

Table 3. *Calculation of the Gini coefficient for line M3*

Stations	**Number of passengers**	***X***	***Y***	**|*X*-*Y*|**	**σ*X***	**σ*Y***	**σ*X*$_{i-1}$ – σ*X*$_i$, (*B*)**	**σ*Y*$_{i-1}$ + σ*Y*$_i$, (*A*)**	***A*×*B***
Lujerului	5.090.341	0,067	0,189	0,122	0,067	0,189	0,067	0,189	0,013
Păcii	4.589.947	0,067	0,170	0,104	0,133	0,359	0,067	0,548	0,037
Politehnica	4.312.695	0,067	0,160	0,093	0,200	0,519	0,067	0,878	0,059
Gorjului	4.189.516	0,067	0,155	0,089	0,267	0,675	0,067	1,194	0,080
Preciziei	3.153.310	0,067	0,117	0,050	0,333	0,792	0,067	1,466	0,098
1 Decembrie 1918	3.090.184	0,067	0,115	0,048	0,400	0,906	0,067	1,698	0,113
Nicolae Teclu	1.131.489	0,067	0,042	0,025	0,467	0,948	0,067	1,855	0,124
Anghel Saligny	763.165	0,067	0,028	0,038	0,533	0,977	0,067	1,925	0,128
Piața Unirii M1+M2	232.968	0,067	0,009	0,058	0,600	0,985	0,067	1,962	0,131
Dristor M1	88.199	0,067	0,003	0,063	0,667	0,989	0,067	1,974	0,132
Timpuri Noi M1	74.962	0,067	0,003	0,064	0,733	0,991	0,067	1,980	0,132
Nicolae Grigorescu M1	71.811	0,067	0,003	0,064	0,800	0,994	0,067	1,985	0,132
Eroilor M1	70.053	0,067	0,003	0,064	0,867	0,997	0,067	1,991	0,133
Izvor M1	51.201	0,067	0,002	0,065	0,933	0,999	0,067	1,995	0,133
Mihai Bravu M1	39.160	0,067	0,001	0,065	1,000	1,000	0,067	1,999	0,133
Total M3	26.949.000	1,000	1,000	1,013	–	–	–	–	1,576

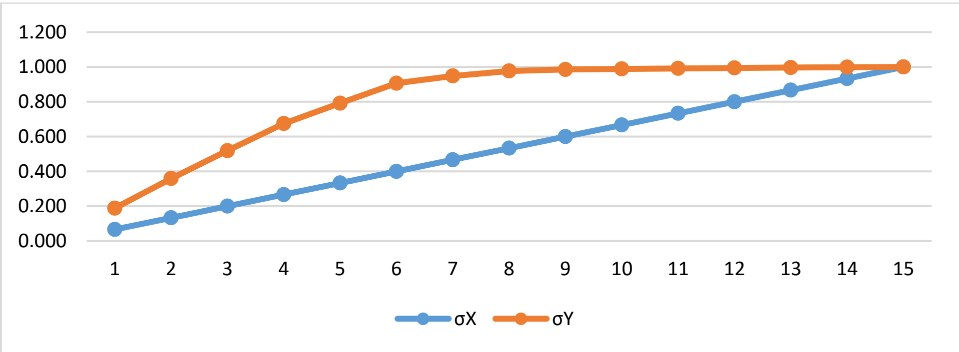

Fig. 8. Lorenz curve for the M3 line

Table 4. *Calculation of the Gini coefficient for line M4*

Stations	**Number of passengers**	***X***	***Y***	**|*X*-*Y*|**	**σ*X***	**σ*Y***	**σ*X*$_{i-1}$ – σ*X*$_i$, (*B*)**	**σ*Y*$_{i-1}$ + σ*Y*$_i$, (*A*)**	***A*×*B***
1 Mai	1.631.501	0,125	0,264	0,139	0,125	0,264	0,125	0,264	0,033
Jiului	938.876	0,125	0,152	0,027	0,250	0,416	0,125	0,680	0,085
Gara de Nord M1	767.237	0,125	0,124	0,001	0,375	0,540	0,125	0,957	0,120
Străulești	689.284	0,125	0,112	0,013	0,500	0,652	0,125	1,192	0,149
Grivița	632.468	0,125	0,102	0,023	0,625	0,754	0,125	1,406	0,176
Laminorului	607.149	0,125	0,098	0,027	0,750	0,853	0,125	1,607	0,201
Parc Bazilescu	538.395	0,125	0,087	0,038	0,875	0,940	0,125	1,793	0,224
Basarab 2 M1	371.090	0,125	0,060	0,065	1,000	1,000	0,125	1,940	0,242
Total M4	6.176.000	1,000	1,000	0,332	–	–	–	–	1,230

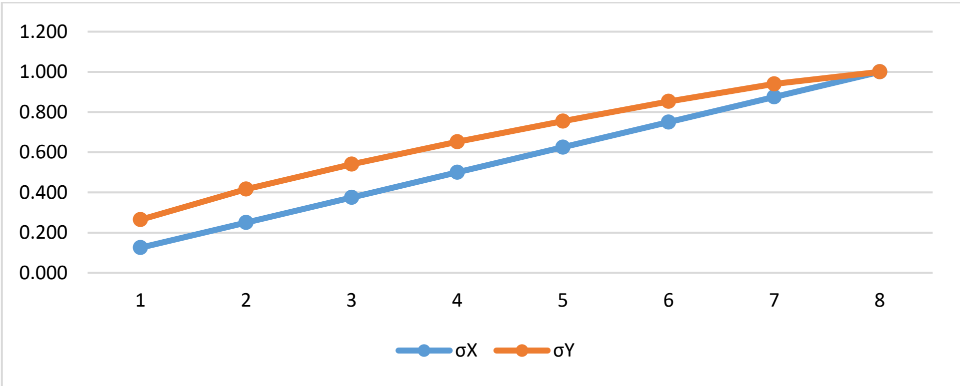

Fig. 9. Lorenz curve for the M4 line

The data in Tables 1-4 demonstrate the calculation of the Gini coefficient. Thus, for the M1 line, the Gini coefficient for this distribution is 0.276 (|1-1.276|), slightly higher than the Lorenz curve, explained by the fact that the line forms a "belt" surrounding the city center, accessing multiple important stations, such as Piața Unirii, Piața Victoriei, Dristor, Obor, Grozăvești, Eroilor.

Table 5 presents the values of the difference index and the Gini coefficient for the year 2019 on all 4 lines in operation, and in Figure 10, the Lorenz curve. For the year 2019, the difference index is 0.315, and the Gini coefficient is 0.353.

Table 5. *Gini coefficient for metro lines M1-M4 in 2019*

Lines 2019	**Thousands of passengers**	***X***	***Y***	**|X-Y|**	**σ*X***	**σ*Y***	**σX_{i-1} – σX_i, (*B*)**	**σY_{i-1} + σY_i, (*A*)**	***A*×*B***
Line M1	76.515	0,25	0,427	0,177	0,25	0,427	0,25	0,427	0,106763
Line M2	69.530	0,25	0,388	0,138	0,5	0,815	0,25	1,242	0,310543
Line M3	26.949	0,25	0,150	0,099	0,75	0,965	0,25	1,780	0,445162
Line M4	6.176	0,25	0,034	0,215	1	1	0,25	1,965	0,491382
Total	179.170	1	1	0,630	–	–	–	–	1,353851

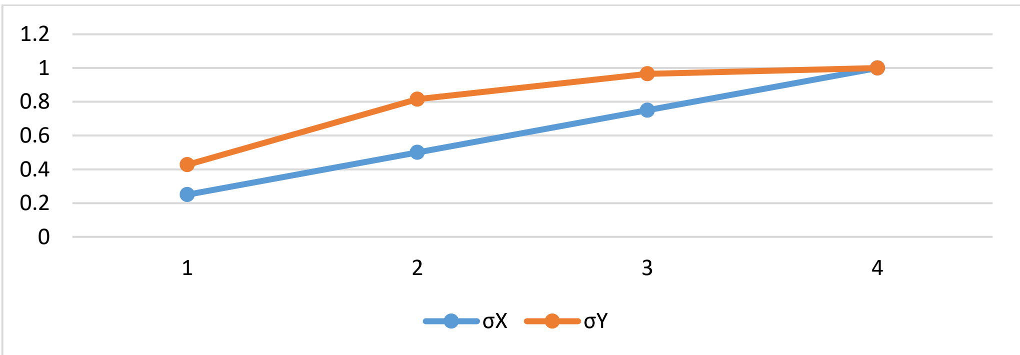

Fig. 10. *Lorenz curve for lines M1-M4 in 2019*

For 2020, the first year of the Covid pandemic, data is presented in Table 6 and Figure 11.

Table 6. *Gini coefficient for metro lines M1-M4 in 2020*

Lines 2020	Thousands of passengers	*X*	*Y*	σ*X*	σ*Y*	σX_{i-1} – σX_i, (*B*)	σY_{i-1} + σY_i, (*A*)	*A*×*B*
Line M1	39.076	0,2	0,432	0,2	0,431693	0,2	0,431693	0,086339
Line M2	33.208	0,2	0,367	0,4	0,798559	0,2	1,230253	0,246051
Line M3	14.509	0,2	0,160	0,6	0,958848	0,2	1,757407	0,351481
Line M4	2.955	0,2	0,033	0,8	0,991493	0,2	1,950341	0,390068
Line M5	770	0,2	0,009	1	1	0,2	1,991493	0,398299
Total	90.518	1	1	-	-	-	-	1,472238

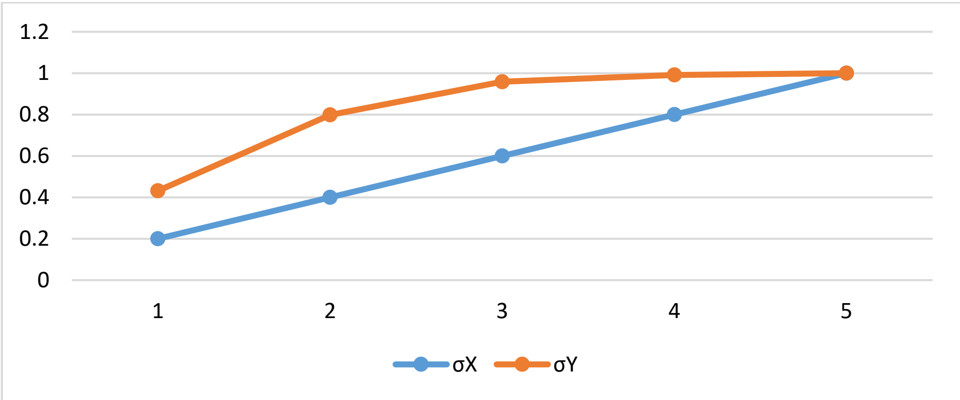

Fig. 11. *Lorenz curve for lines M1-M5 in 2020*

5. CONCLUSIONS

Applying the Gini coefficient method, the following types of problems can be addressed:

- using traffic information, calculate the difference index ID and the Gini coefficient G in the entire research area;
- plot the Lorenz curve for both distributions;
- using the difference index ID and the Gini coefficient G, draw conclusions about the level of traffic concentration;
- comparatively analyze the differences (or similarities) of traffic concentration in both situations.

The quantitative analysis confirms that the Gini index is a statistically and quantitatively significant determinant of socially optimal supply variables. This implies that if demand imbalances are neglected in a public transport model based on a representative pair of optical diagrams, then the optimal capacity, especially vehicle size, is slightly underestimated.

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