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Statistical Analysis for Efficient Design of Passenger Transit System

G. Giorgobiani[a] T. Giorgobiani[b], K. Kandelaki[c], V. Kvaratskhelia[a∗], M. Tsatsanashvili[d]

[a]*Muskhelishvili Institute of Computational Mathematics, Georgian Technical University, Gr. Peradze str., 4, Tbilisi 0159, Georgia*;

[b]*Faculty of Psychology and Educational Sciences of I. Javakhishvili Tbilisi State University, 11 Ilia Tchavtchavadze Avenue, Tbilisi 0179, Georgia;*

[c]*Faculty of Business Technologies, Georgian Technical University, Kostava str., 77, Tbilisi 0160, Georgia.*

[d]*Research Institute of Public Administration, Georgian Technical University, Kostava str., 77, Tbilisi 0160, Georgia*
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In this work we investigate performance of the bus transit system of city Tbilisi based on the statistical analysis of the passenger flow during the year 2019. In order to detect the changes in the system during the transitional period 2018–2019, some statistics of the mentioned period are compared with that of 2017, investigated by the joint research project of Tbilisi City Hall and an international engineering and consulting group SYSTRA. Passenger flow during 2019 is also analyzed with regard to the working and festive days and by seasonal trends as well.

Keywords: Bus transit system, passenger flow, Wilcoxon test, Mann-Whitney test

AMS Subject Classification: 97K80

1. Introduction

In the recent years a set of various measures for the improvement of the urban transport system of Tbilisi, capital of Georgia, have been performed.These changes are in line with the Sustainable Urban Transport Investment Program SUTIP, conducted in the frames of cooperation of Georgia and Asian Development Bank (ADB), which is the basis for the Strategy of Sustainable Urban Development of Tbilisi (2015–2030). And two of the main tasks is the renovation of the municipal bus fleet and reorganization of the bus route system, which have started in 2017. Naturally arises a question about the efficiency of the conducted activities in this respect during the elapsed period.

In this work we present statistical analysis of the performance of M3 bus transit system (BTS) based on the passenger flow (PF). PF is the number of passengers transferred via the BTS per day, week, month or per year. We analyze the performance of the system during the 12 months of the year 2019 (*Period* 1 below) for

∗Corresponding author. Email: v.kvaratskhelia@gtu.ge

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111 bus routes, existing at that time. Note that the similar research is contained in [1], where the present methods have been tested for the reduced data. Having at the hand as well reports of the joint research project of Tbilisi City Hall and an international engineering and consulting group SYSTRA [2], containing the analysis of BTS for 11 months of the year 2017 ($Period$ 2 below), in Section 4 we were able to compare some statistical parameters over these two periods. This in its turn gave possibility to identify and quantify the changes, possible improvements or drawbacks, of different segments of the system during the transitional period 2018–2019.

In Section 5, PF in $Period$ 1 is analyzed with regard to the working and festive days and by the months as well. The natural seasonal trends are also identified and quantified.

2. Data collection

Data for the $Period$ 1 comprises the period of 12 months, starting from January 1 up to December 31, 2019. The part of it has been kindly provided by the Tbilisi Transport Company officially, some details were collected through the other sources like internet, personal communication, etc. This data, labeled by $P1$, contains the daily passenger transfers for 111 bus routes, operating for that period.

Data for the $Period$ 2 is collected from [2]. It comprises information about the total transfers and the monthly averages for each of 102 routes, operating for the period of 11 months in 2017.

The monthly average transfers by the route for both of the periods are calculated by averaging the total annual PF by 12 and 11 months respectively (i.e. total is divided by 12 or 11).

3. Methodology

In Section 4, performance of BTS is compared for two periods. Due to intensive innovation process of the system during the transitional period, improvements are naturally anticipated. Thus we have planned to compare what was before with what do we have now, after the measures that were conducted by the authorities of the city. As we did not have at hand data of the daily performance of TBS in $Period$ 2, this problem was considered only for the annual and monthly PF-s.

In section 5 we analyze this data with respect to the daily, weekend and seasonal performance. For this reason, 45 bus routes from the network of routes of the city of $Period$ 1, have been chosen randomly as follows: 10 routes from top 20 most loaded routes, 10 from the 20 routes with minimal passenger loads and 25 from the middle category.

For the analyses we group the data in 3 segments of PF, top, low and middle, for the both of periods. We considered PF in different time-modes (weekends and working days, summer and ordinary months). It occurred that mostly the data are not distributed normally. For the comparison of related samples form 2 periods, the Wilcoxon nonparametric test is applied. Regarding the data in one period, the segments can be assumed as independent samples and, thus for their comparison we apply the nonparametric tests of Kruskal-Wallis and Mann-Whitney for the independent samples.

To test the normality of the distributions, both Shapiro-Wilk and Kolmogorov-Smirnov normality tests are taken into account.

Below, everywhere we use 5% confidence level for the hypothesis testing. The null Hypothesis H_0 as a rule assumes that two samples (specified in each problem accordingly) are drawn from one and the same population, while the alternative hypothesis H_1 rejects this assumption.

Statistical analysis is performed applying *SPSS* Statistics. Some visualization tools of Excel have been used as well.

4. Comparison of Periods 1 and 2. Distribution of the city policy measures with respect to the different segments of the bus transit system

In this section we analyze some features of PF in the municipal bus system of the city, based on the information on the daily passenger flow during the *Period* 1. For the given period of time, there were in total 111 bus routes operating with the fleet consisting of about 560 vehicles. Obtained statistics will be compared with that of given in the document [2], where the first 11 months of year 2017, *Period* 2, are considered as the time period of research for 102 bus routes operating for that time period mostly by the worn out vehicles.

Total PF for the *Period* 1 amounts to more than $F_a = 130 \times 10^6$ transfers with monthly average about $\bar{F}_m = 10.8 \times 10^6$ and the daily average about $\bar{F}_d = 0.363 \times 10^6$ transfers.

According to [2], total PF for *Period* 2 (11 months) was about 101×10^6, corresponding monthly average $\bar{f}_m = 9.4 \times 10^6$ and daily average about $\bar{f}_d = 0.314 \times 10^6$ transfers. As the monthly PFs therein are defined as the averages by the 11 months, we correct the PFs by routes by adding the corresponding monthly averages and use the changed data as the annual data for $P2$. Thus the corrected annual PF for *Period* 2 (12 months of year 2017) would be about $f_a = 110.7 \times 10^6$.

As we see, there is a large difference between the figures by the periods:

$$F_a >> f_a, \quad \bar{F}_m >> \bar{f}_m, \quad \bar{F}_d >> \bar{f}_d.$$

The increase of these parameters might be explained by the improvement of the bus system during the transition period 2018 - 2019 when 9 new bus routes and extra new vehicles, partially substituting old ones, were added to the system[1].

Is this deference statistically significant? To make in-depth analysis, we consider annual and monthly bus route transfers and compare them for the *Periods* 1 and 2.

Note first of all that for the *Period* 2 we have in all 101 pairs of data respectively for the annual PF and monthly PFs of the bus routes (data for the route #35 is missing from total 102 routs). From 101 routes, 3 routs (##111, 152, 153) were amended during the changes in 2018 - 2019. For the *Period* 1, we have 110 pairs of data from 111 routes, existing for that period (excluding route #35). These data are labeled with $P1$ and $P2$ respectively. Common 98 routes are labeled as "common" and extra 12 routes of *Period* 1 as "extra".

[1]In fact, 12 new routes have been added and 3 amended.

4.1. General analyzes of annual and monthly PF in $P1$ and $P2$

In this Subsection we analyze the performance of BTS by annual and monthly PFs in the groups $P1$ and $P2$.

Table below is the summary information about the variables considered in this section:

Variables in Section 4	
Independent variables (routes)	**Dependent variables (PF)**
Bus routes P1	annual P1, monthly P1, daily P1
Bus routes P2	annual P2, monthly P2
Common bus routes by the segments (low, middle, top)	low-common-annual P1, middle-common-annual P1, top-common-annual P1; low-common-annual P2, middle-common-annual P2, top-common-annual P2, etc.

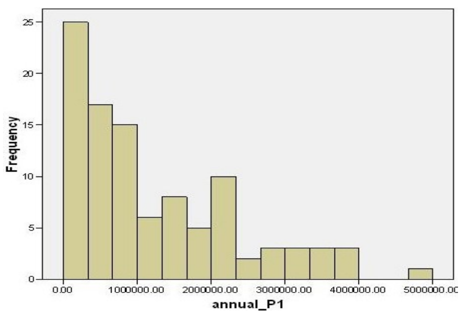
Table 4.1

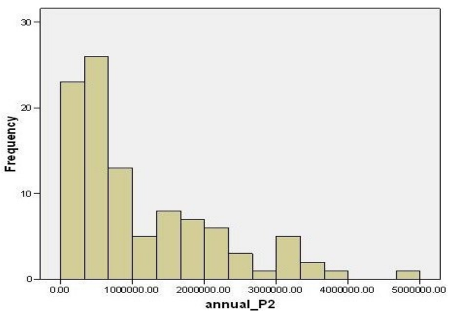
For the annual and monthly passenger transfers by the routes $P1$ and $P2$ we have the following descriptives:

Descriptives(ann/month)		
Statistics	**Period 1**	**Period 2**
Mean	1,180,000/1,02,538	1,090,000/93,331
Median	726,000/64,390	675,000/58,868
St.D	1,090,000/91,047	1,030,000/87021
Maximum	4,781,108/398,425	4,710,929/392,577
Minimum	15,912/1326	6,235/520
Skewness	1.078/1.078	1.263/1.199
St. Err.	SE 0.240	

Table 4.2

As seen from the descriptives, mean values and the medians and other statistics as well, are increased. Due to Shapiro-Wilk and Kolmogorov-Smirnov tests, none of the 4 samples are normally distributed. Visual inspection and the large skewness ratios confirm the statement. Two histograms for annual data are given as an example (the histograms for monthly data are much the same):





For more detailed analyzes regarding the distribution of the improvement measures with respect to the different segments of the system, we have considered 3 groups from each data: top 20 most loaded routes, 20 routs with lowest passenger loads and the middle routes, that do not belong to any of previous 2. These 3 categories are denoted respectively by "top", "middle" and "low". Data in each category are the annual (or monthly) passenger transfers per rout in Periods 1 and 2 respectively. Some descriptives for annual PF are in the table below (monthly PF possess the same pattern):

Segments (Period 1/Period 2)			
Statistics	**low**	**middle**	**top**
Mean	152926/127861	1037376/848604	3083203/2818960
Median	156348/141643	888214/675177	3116755/2589176
St.D	75699/74873	561901/485409	666233/725240
Maximum	263536/249203	2117951/1838737	4781108/4710929
Minimum	15912/6235	344729/254860	2177059/1995149
Skewness	-0.302/-0.136 (SE 0.512)	0.683/0.764/(SE 0.306)	0.680/0.945/(SE 0.512)

Table 4.3

Exploration shows that, though due to the Shapiro Wilk and Kolmogorov Smirnov tests, significance of the normality assumption is high in the segments top and low, we cant regard them as such. The normality assumption is rejected in the middle segment as well.

Note also that 6 routes from the 12 of the extra group, are positioned in the low 20 segment of P1. Their mean annual PF equals 112,489, which is even less than 152,926, the mean of the total low segment routes. These routes are relatively short and often operate in the remote districts of the city with less than 675,000 transferred passengers per year for the whole group. Six other extra routes are situated in the middle segment, mostly in its lower part. The whole extra groups 12 routes transfer in average a little more than 340,000 passengers annually. In Period 1, their total transfers amounted to only 4 million. The table below shows the percentage contribution of each segment in the total transfers:

Percentage/annual		
Segments	**Period 1**	**Period 2**
top	47.2%	50.9%
low	2.3%	2.3%
middle	50.5%	46.8%

Table 4.4

4.2. Comparison of $P1$ and $P2$ by the related samples nonparametric test

To investigate the significance of the changes of the performance of BTS over the two periods, we analyze the PF of the group of 98 common routes for both of periods.

Both Shapiro-Wilk and Kolmogorov-Smirnov normality tests and visual inspection as well, show that none of the variables are normally distributed. Thus for the comparison we use nonparametric Wilcoxon Signed Rank test for the related samples. Let us compare the annual data. Wilcoxon Signed Rank test shows the difference between the positive and negative ranks with 2-tailed asymptotic significance 0.000 (see the table below):

Wilcoxon Signed Rank test (common annual P2 - P1)			
Ranks	**N**	**Mean Rank**	**Sum of Ranks**
Negative ranks	92	59	4498
Positive ranks	6	49	353
Ties	0		
Total	98		
Z	-7.34		
asymp. significance	0.000		

Table 4.5

As a result, we conclude that the annual performance of BTS in $P1$ is significantly higher than that of $P2$. Thus the overall annual performance is improved significantly in Period 1.

In [2], analyses of top 20 routes monthly PF is given. That is why, to compare the performance of the segments by the periods, we choose the monthly data.

Let us do complete analyses for the top segment. Top 20 most loaded routes of Period 1 almost coincide (2 exceptions) with the corresponding top 20 of Period 2 given in [2]. Top 18 common routes, together with corresponding monthly top segment averages are given in the Table 4.6 below (data is visualized in Figure 1):

top 20 routes (passenger/month)		
route no.	**Period 1**	**Period 2**
2	322038	268338
11	183879	186975
14	278582	199857
20	252885	206353
21	279442	244037
23	266574	263623
24	271253	251705
33	229228	223534
37	291391	207996
39	309445	259943
51	398426	392577
55	223229	167997
70	192738	153228
71	222125	182512
88	320197	302222
95	220300	192790
101	186877	178072
150	270624	271757

Table 4.6

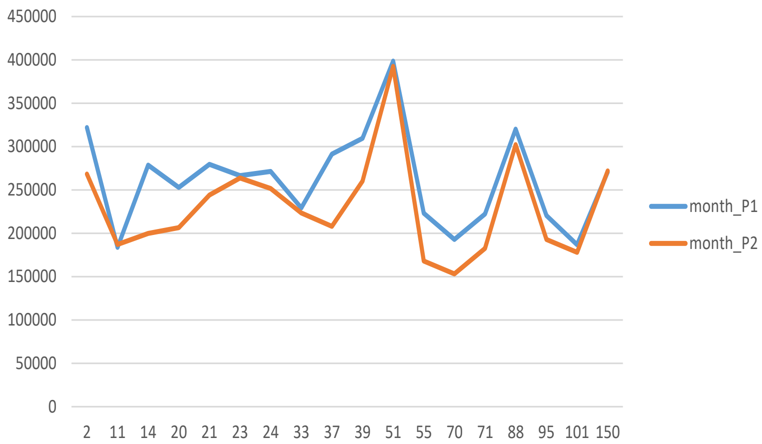


Figure 1. Top common routes

We see that the PF for all of the common routes, except the routes 11 and 150, is increased during the Period 1. In the Table 4.7 some statistics for 18 common top routes are given:

Statistics for 18 common top routes		
Statistics	**Period 1**	**Period 2**
Mean	262179	230750
Median	268599	215765
St. D	55312	58140
Maximum	398425	392577
Minimum	183879	153228
Skewness	0.628 (SE 0.536)	1.223 (SE 0.536)
Pearson Correlation	0.892	

Table 4.7

Test for normality shows that the null-hypothesis that both of the samples are Normally distributed can't be rejected (see the table below):

Shapiro-Wilk Normality test (top20 - P2/P1			
	Statistic	**df**	**Sig**
top-P2.month	0.909	18	0.084
top-P1.month	0.949	18	0.415

Table 4.8

Skewness for the top category is positive for both periods, $S_1 = 0.628, S_2 = 1.223$, with the standard error $SE = 0.536$. The ratio for Period 1, $S_1/SE = 1.17$, is within the interval ± 1.96. Thus we cant reject that the top group for Period 1 is normally distributed. Visual inspection agrees with the upper statements for Period 1. Thus we conclude that the top segment of Period 1 is approximately normally distributed. The ratio for Period 2, $S_2/SE = 2.28$, is outside the interval ± 1.96. Visual inspection also confirms that the top segment of Period 2 is not approximately normally distributed.

Thus for the comparison of 18 top common routes, nonparametric Wilcoxon Signed Rank test was applied.

Wilcoxon Signed Rank test (18 top common routes P2-P1)			
Ranks	**N**	**Mean Rank**	**Sum of Ranks**
Negative ranks	16	10.44	167
Positive ranks	2	2	4
Ties	0		
Total	18		
Z	-3.6		
asymp. significance	0.000		

Table 4.9

As a result, we conclude that the monthly performance of top common routes of $P1$ is significantly higher than that of $P2$. Thus the overall annual performance is improved significantly in Period 1. Positive skewness may indicate that often the quantity of transferred passengers is more than the average monthly PF per route. Analyzes for the other pairs is similar. The test statistics results in very low $p-values$, less than 0.05. This yields that the data in each pair significantly differ from each other.

Conclusions. Upper estimations and arguments lead to the conclusion that there were performed changes in the overall bus transfer system during the indicated time period. Improvements are significant in all segments. Monthly averages of PF are increased in every segment. Standard deviations are quite large in top and middle segments and relatively small in the low segment. This indicates about the unstable performance of BTS in top and middle segments in the both periods. Regarding the skewness, they have the same signs within the segments. The negative skewness of the low segment may indicate that often the quantity of transferred passengers is less than the average monthly PF per route. On the contrary, positive skewness of top and middle segments may indicate that often the quantity of transferred passengers is more than the average monthly PF per route.

5. Daily performance and seasonal trends for Period 1

To analyze the daily performance of BTS in $P1$, seasonal trends etc., we have chosen randomly 45 bus routes, from total 110 routs of the city: 10 routes from the top 20 routes with highest loads, 10 from the 20 routs with lowest loads and 25 from the middle. Below, four variables are denoted respectively as: low, top, middle, Total. In each variable we store the daily average PF-s of routes of the corresponding segment. For the comparison we apply the Mann-Whitney test.

Table below is the summary information about the variables considered in this section:

Variables in Section 5	
Independent variables (routes)	**Dependent variables (PF)**
Low routes	weekend-low, working-low/ summer-low, ordinary-low
Middle routes	weekend-middle, working-middle/ summer-middle, ordinary-middle
Top routes	weekend-top, working-top/ summer-top, ordinary-top

Table 5.1

5.1. Daily performance by the route segments

Table 5.2 summarizes some statistics:

Daily Statistics	low	middle	top	Total
Mean	415	2398	8651	3821
Median	422	2472	8787	3903
St.D	87	491	2144	896
Maximum	628	3266	11949	5152
Minimum	64	382	1338	603
Skewness	- 0.704	- 0.966	- 0.612	- 0.703
Standard Error	SE 0.123			

Table 5.2

As we see, statistics for the groups low, top and middle impressively differ from each other. Is the difference statistically significant between the groups? To answer this question, note first that Shapiro-Wilk normality test shows that none of the groups are normally distributed. In this case the segments can be regarded as independent samples. The segments low, middle and top are merged in one variable "low-mid-top" and coded as 1, 2 and 3 respectively in the grouping variable "group-l-m-t". First we apply the Kruskal-Wallis nonparametric test, which gives that the difference in at least one pair is significant ($p = 0.000$). For the details we apply the Mann-Whitney test, which shows that there is significant difference between the data in each pair, with very small $p - values(= 0.000)$.

As a conclusion for this part, we can say that BTS operates in significantly different modes throughout the chosen 3 segments. Table 5.1 shows that all statistics (except the skewness) increase significantly across the segments. Standard Deviation is largest in the top category, meaning that the daily PF is highly non-stable in this group. The negative skewness of all the samples may indicate that often the quantity of transferred passengers is less than the average daily PF per route.

5.2. Analyzes by the weekends and working days

The summary of descriptives for the weekend and working days performance of BTS by the grouped routes is given in the Table 5.3 below:

Performance Weekend/Working				
Statistics	**low**	**middle**	**top**	**Total**
Mean	348/442	1914/2590	6513/9494	2925/4175
Median	347/448	1927/2715	6326/10021	2861/4469
St.D	59/82	247/429	1125/1844	460/771
Maximum	524/627	2427/3266	8499/11948	3703/5152
Minimum	90/63	382/396	1337/1464	603/641
Skewness weekend	- 0.366	- 2.057	- 0.612	- 0.866
St.Err. weekend	SE 0.228			
Skewness working	- 1.422	- 2.300	- 1.646	- 1.838
St.Err. working	SE 0.145			

Table 5.3

Shapiro-Wilk normality test shows that none of the groups are normally distributed. Comparing the means in Tables 5.3, we get that PF decreases considerably on the weekends. The percentages of decrease by the segments of BTS are given in the Table 5.4,

Decrease percentage Weekend/Working				
	low	middle	top	Total
Mean	21%	26%	31%	30%

Table 5.4

which shows that the decrease is maximal in the top segment.

Here, we apply the Mann-Whitney test again. For this reason, we introduce a new grouping variable "grouping-weekend-work" coded with 0 and 1, corresponding to the weekend and working days respectively. Test shows that there is significant difference between the weekend and working days transfers in each segment of BTS (with very small $p - values (= 0.000)$).

Figure 2 visualizes the change of PF during the week in all segments.

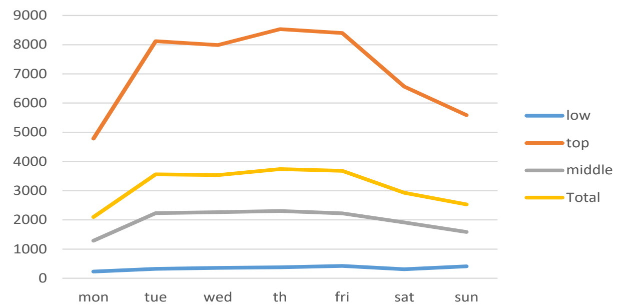


Figure 2. Weekend and working days PF

5.3. Analyzes of PF by the summer months. Seasonal trend

In this part the data is broken into 2 groups: from the 12 months of 2019, 2 months, namely July and August are regarded as the summer low activity, vacations season, and are grouped in the summer group. The rest 10 months are grouped separately in the ordinary group. We analyze daily PF by these 2 groups and by the 3 segments of BTS. The descriptives for both groups are given in the Tables 5.5.

Performance Summer/Ordinary				
Statistics	low	middle	top	Total
Mean	417/423	2108/2482	6945/9083	3157/3996
Median	422/431	2096/2698	6930/10050	3153/4426
St.D	50/87	270/488	1140/2079	483/874
Maximum	592/627	2595/3266	8944/11948	3970/5152
Minimum	317/63	1568/382	4791/1337	2230/603
Skewness Summer	0.424	- 0.205	- 0.124	- 0.149
St.Err. Summer	SE 0.306			
Skewness Ordinary	-0.671	-1.229	-0.952	- 1.031
St.Err. Ordinary	SE 0.140			

Table 5.5

The percentages of decrease of means and medians by the segments of BTS are given in the Table 5.6.

Decrease percentage Summer/Ordinary				
	low	middle	top	Total
Mean	1.4%	15%	23.5%	21%
Median	2.1%	22.3%	31%	28.8%

Table 5.6

We see that the rate of decrease of PF in the summer months is less impressive than by weekends. It's most striking that in the low segment the changes for the median and the mean are almost negligible and equal 2.1% and 1.4% respectively.The histograms of summer and ordinary transfers in this segment have approximately similar shapes.

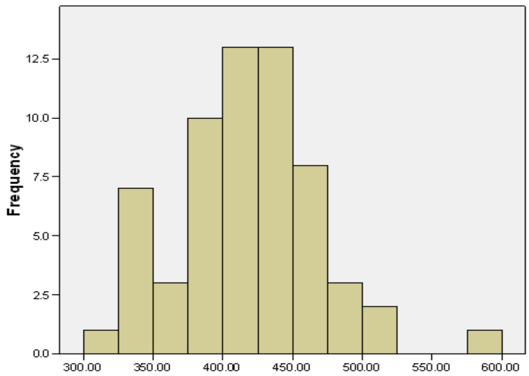


Figure 3. Summer transfers in a low segment

Mann-Whitney test for 2 independent samples shows, there is now significant difference in the low segment with regard to the Summer and Ordinary months, while its significant in all the rest of the segments (see Table 5.7).

Mann-Whitney test Summer/Ordinary				
Test Statistics	**low**	**middle**	**top**	**Total**
Mann-Whitney U	9839	5307	4426	4687
Asymp. Sig. (2-tailed)	0.645	0.000	0.000	0.000

Table 5.7

Figure 4 below visualizes the change of PF throughout the 12 months of 2019.

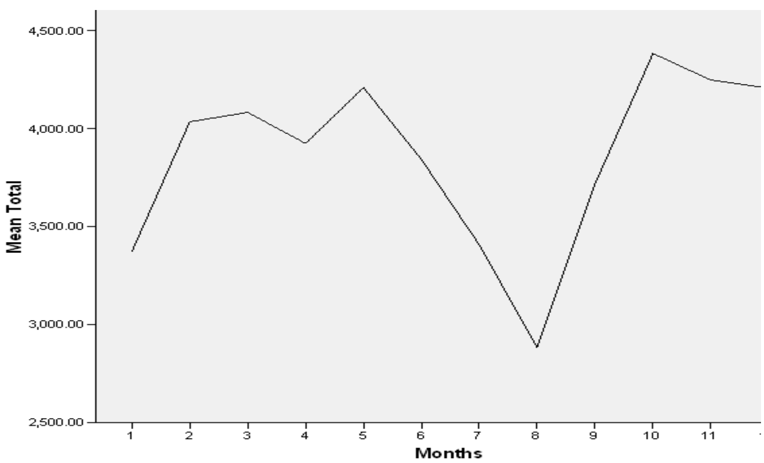


Figure 4. PF in 2019

6. Conclusions

As a conclusion of this part, we can say that the daily performance of BTS is significantly different throughout the chosen 3 segments. Table 5.1 shows that the mean, median and Standard Deviation increase in upper segments and decrease towards the weekends and summer months. SD is largest in the top segment, meaning that the daily PF is highly non-stable in this group. Comparing the mean PF in the week days we get that PF decreases impressively by the weekends, e.g. in the top segment it decreases by 31%.

As to the means in the seasonal summer and ordinary groups, largest fall is in the top category and equals 23.5% and most interestingly, there is no significant difference in the low segment, which equals 1.4%. Investigation of the reasons for such behavior is perhaps a subject of other disciplines, like social sciences, and is beyond the scopes of this paper. As a recommendation we suggest that for the routes with low PF, in order to ensure the effective organization of passenger transit, the quantity of operating vehicles should be equal along the whole year disregarding the summer and ordinary seasons. The negative skewness of all the samples may indicate that often the quantity of transferred passengers is less than the average daily PF per route.

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