Forecasting People's Influx on Mexico City Metrobus Line 1 Using a Fractal Analysis

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Abstract. Metrobus Line 1 user's influx has increased significantly year by year since its operations beginning at 2005, the amount of Metrobus users increase day by day in every line, even with new routes and most BRT unit, it menas that Metrobus system has not a prospective model to determine the amount of users that the system will have every month and with this information, stablish an improvement planning to avoid user's delays. This paper presents a fractal analysis of Metrobus line 1 users influx as a forecast model that allows us to know the people increase and the impact it will have in the future to help in the decision making process with an ARFIMA model to predict Metrobus Line 1 user's monthly influx for every month during years 2020, 2021 and 2022, analyzing their behavior Metrobus line 1 infrastructure planning including rides, stations extension and user's limit can be improved.

Keywords: Forecast · Fractals · ARFIMA · BRT · Mexico City

1 Introduction

According to Metrobus webpage, the central part of a city development is an effective public transport system. For most of cities population, public transportation is the only way to access employment, education and public services [1]. This means that a set of movements of people are made through various modes of transport [2]. Thus, at the end of the day, literally millions of journeys in our city are produced.

Another definition is the movement of people from one point to another and regardless of the means by which it moves, has different consequences to them, because of this, it is desirable to separate the consequences into two groups: the consumption of resources

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and environmental impacts [2]. The word mobility means in extension the consumption of various non-material and material resources. The first consumption is non-material and is related to the time people spent moving from one point to another, the time is a non-renewable and worthy resource for people. Reducing travel time to the lowest possible level will always be the goal of transport service users. Second one is space, mobility requires space in order to build the transport infrastructure and space when people use it. I.e. sidewalks, freeways, bus terminals, railway stations and railways that occupy a huge physical space, cost of construction and maintenance is paid by society through their taxes. In the other hand, people consume different amounts of road space when they are using different modes of transportation and consume energy, which is wasted by all motorized or electrified vehicles, it is worth mentioning that public transport such as metro and trolleybus uses electricity, while the BRT systems, in Mexico City case called Metrobus and private vehicles, use fuel. And the third one is the financial resource, i.e. road maintenance costs, traffic signals and operation, the living of the police assigned to these tasks and, in the case of owners of means of transport, maintenance of the same.

1.1 Mobility Transport Problems and Bus Rapid Transit System (BRT)

The movement of people from one point to another and regardless of the transport means by which it moves, has different consequences for those who live in the same environment that is why it is convenient to separate these consequences into two groups: resource consumption and environmental impacts.

Talking about mobility is necessary to talk about the consumption of various tangible and intangible assets. The first intake is not material and is related to the time spent in traveling from one point to another, since time is a nonrenewable resource for people. Reducing travel time to a minimum is always the objective of the transport services users. The second one is the space, mobility demands space when it is necessary to build the transport infrastructure and when people use that infrastructure. Examples are, sidewalks, highways, bus terminals, train stations and railways that occupy a large physical space, the cost of construction and maintenance is paid by the society through their taxes. In the second case, people consume different amounts of circulating space when they are using different ways of transportation. The third one is the energy consumed by all motorized or electrified vehicles including public transportation such as subways and trolleybus that uses electricity, meanwhile Metrobus and private vehicles, as well as private transport use fuel. The fourth one is financial resources, such as road maintenance costs, signs and traffic operation, talking about the police entrusted with the transport tasks and in the case of the transport means owners, the maintenance [2].

The use of motorized vehicles involves several forms of atmospheric and sound pollution too, six types of air pollution related to transportation are identified [3]:

a) Sensitive contamination: perceived by people through the smell and vision because the source is close to the person.
b) Contamination affecting human health: The presence of pollutants such as CO, nitrogen oxides and hydrocarbons.
c) Photochemical Smog: The presence of contaminants in the atmosphere.
d) Acid rain: The main consequence is the damage caused to forest areas.

e) Effect of the ozone layer on the planet's poles.
f) Greenhouse effect, caused mainly by CO_2 concentration in the atmosphere.

1.2 Traffic Congestion

Traffic congestion is a condition that occurs in the roads and characterized by very low speeds, detriment in travel times, and considerable increase of vehicles lines [4, 5]. There are a number of specific circumstances that generate or aggravate congestion; for example, the volume of traffic, works on roads, weather events (e.g., flooding roadways) and most of them attributed to the occurrence of road accidents. The traffic road research has revealed that still cannot fully predict in what conditions suddenly a traffic jam can occur [5]. However, it has been found that accidents can cause cascading failures that spread to other roads later (and other modes) and create a sustained traffic jam [4, 5]. It is clear that traffic congestion has a number of negative effects [6]:

a) waste of time for drivers and passengers; i.e. as a productive activity for most people, congestion reduces economic health of the city;
b) delays, which can lead to late arrival of employees to meetings and education, resulting in lost for business, disciplinary measures and other personal losses.
c) fuel waste and increased CO_2 emissions, causing air pollution due to increased 'rentelí', acceleration and braking;
d) issues on emergencies: blocked traffic can interfere with the emergency vehicles circulation when they are traveling to their destinations where are urgently needed;
e) high probability of collisions due to the space between vehicles and trucks as well as the constant stops and 'starts' to advance during a road congestion.

2 Urban Mobility in Mexico City BRT System

Urban mobility, is still dominated by the "car culture" [7]. Motorized models, on the other hand, produce air and noise pollution as well as accidents and congestion. In the late 90's and early XXI century, Mexico City had been affected by the lack of efficient transport services.

This is due to excessive population growth in the city and traffic problems in main avenues for the huge number of cars and the collapse in the urban transport system [8]. In the year 2005 starts the new massive transport system called Metrobus along one of the main avenues with 30 km long (Metrobus line 1). It is believed that Metrobus system improved mobility by 50%; given immediate benefits of mobility, thousands of users decided to make a modal shift from private vehicles to public transport. The success of line 1 led to the opening of more lines, as the lines 2 (2008), 3 (2011), 4 (2012), 5 (2013), 6 (2016) 7 (2018). Other extensions area planned and under construction. Currently, the seven lines together cover a length 140 km over Mexico City and carrying about 1, 400,000 users daily (See Table 1) [9].

Traffic accidents are a serious public health problem. They are the leading cause of death among 15–44 aged men and the fifth leading cause of death for women in the

Table 1. Some features of Mexico City Metrobus Transport System

Features	L1	L2	L3	L4	L5	L6	L7	Total
Length	30 km	20 km	17 km	28 km	10 km	20 km	15 km	140 km
Operations start	June 2005	Dec 2009	Feb 2011	April 2012	Nov 2013	Jan 2016	Feb 2018	–
Stations	44	34	29	32	16	35	29	219
Users/Day	480000	180000	140000	65000	55000	150000	130000	1,4000,000

same range. A 2004 World Health Organization report states that 1.2 million of deaths worldwide occur because of traffic accidents, with more than 50 million people injured.

The costs of accidents are extremely high and are 1% to 2% of countries' Gross Domestic Product. The estimated annual cost around the world is USD 518 billion and is concentrated in the rich countries of high motorization. Despite this, all studies show that the problem tends to worsen in developing countries, as the motorization of their societies grows, especially when the transit environment and the society itself are not prepared for this sudden increase [10].

In order to carry out an exhaustive review concerning the constant accidents that occur in BRT systems and the way in which these affect the urban mobility and the potential users, it is important to consider that a greater part of the Mexico City BRT system accidents occurs at intersections, either due to vehicular and pedestrian influx or other factors [11].

Consulted data sources are reports obtained through infomex web page [12–17], provided by the public security secretary, Metrobus system reports, newspapers articles, collision videos of video streaming sites and other electronic media from 2005 to present [18–20]. Research on BRT has been reported in literature of several issues; for example, from an economic perspective [6, 21, 23, 35], social perspective [22, 27–29, 31], technical performance [23–26, 30], environmental perspective [21, 34], road safety [24, 36] and accident analysis [18–20], however, there are few studies being conducted explicitly on BRT user's mobility forecast [36–40], data analysis or improvement [32, 33].

According to this, it is necessary to predict the number of users in order to avoid congestions in the BRT stations due users at different peak hours, (see Table 2).

Metrobus line 1 have three peak hours per day every week:

'Peak-Hours' (PH) in Line 1:
06:00 hrs $\leq$ PH-Early Morning $\leq$ 08:00 hrs
13:00 hrs $\leq$ PH-Afternoon $\leq$ 15:00 hrs
17:00 hrs $\leq$ PH-Until Early/Night $\leq$ 20:00 hrs

Artificial Neural Networks (ANN) are a good mathematical tool for forecasting, but one of ANN limitations is that a big amount of historical data is required to train it; therefore, it gives guideline of not selecting ANN to make forecast of Metrobus Line 1 user's influx instead of fractals, that have an advantage on analyzing smaller amounts of historical data and they are an excellent tool for this cases.

Table 2. Mexico City Metrobus Transport System line 1 users per year [8, 9].

2005	37,049,149
2006	74,321,914
2007	77,505,395
2008	89,201,679
2009	93,455,128
2010	99,342,235
2011	109,164,875
2012	122,082,471
2013	124,891,960
2014	127,044,608
2015	133,475,705
2016	135,570,009
2017	136,980,154
2018	152,395,710
2019	157,256,938
Total users	**1,669,737,930**

3 Methodology

To focus on influx for years 2020, 2021 and 2022 of Metrobus Transport System, the Fractal Dimension "D" will be used. The Fractal Dimension is a numerical quantity that serves to characterize and even classify fractal objects, a generalization of the Euclidean dimension, so an object is fractal only when its dimension is greater than its Euclidean dimension and allow us to determine if model can be used with history of total monthly user influx from 2008 to 2019 data. Besides, fractal dimension is the main element to apply ARFIMA model to historical data and know Metrobus Line 1 influx forecast, the fractal dimension (D) is given by:

$$D = 2 - H \;||\; H = Hurst\ Coefficient \tag{1}$$

It means:

$$d = H - \frac{1}{2} \tag{2}$$

Where
d = Fractional integration parameter
H = Hurst coefficient

The fractional integration parameter (d) establishes the following behaviors for the time series:

- If $0 < d < 0.5$ the Auto Regression, Fractional Integration and Moving Average (ARFIMA) process is a stationary process of long-term memory. In this case, the auto-correlations are positive and decrease hyperbolically towards 0 depending on the delay.
- If $d = 0$ the ARFIMA process is reduced to an ARMA process, and does not present any long-term memory structure.
- If $-0.5 < d < 0$ the ARFIMA process is an antipersistent process. In this case, the autocorrelations alternate the sign.

To calculate Fractal dimension (D) Benoit 1.2 software is used, it is a commercial computer program that enables to measure the fractal dimension and/or hurst exponent of data sets using different methods in for 2D data such as ruler, box, information, perimeter-area, and mass for analysis of self-similar patterns; Fractal Dimension D is obtained with Box-Dimension technique based on the history of total monthly user influx from 2008 to 2019. Once fractional integration parameter (D) is available, the ARFIMA model will be applied in ITSM2000 commercial software.

3.1 Influx User's Analysis

The calculation of the fractal dimension (D) uses the Box-Dimension technique of the influx of Metrobus. Line 1 with the historical data of Table 2, The historical data was plotted in Excel because the software only can read data in bmp format, so it was saved as a bmp fil using paint software (See Fig. 1).

$$\textit{Hurst Coefficient}\ (H) = 2 - D = 2 - (1.43009) \tag{3}$$

Thus:

$$\textit{Fractal Dimension}\ (D) = 1.43009 \tag{4}$$

To calculate Fractional Integration Parameter:

$$(d) = H - \frac{1}{2} = 0.56991 - \frac{1}{2} = 0.06991 \tag{5}$$

Thus, Fractional Integration Parameter (d) is in the following range:

$$0 > d < \frac{1}{2} \tag{6}$$

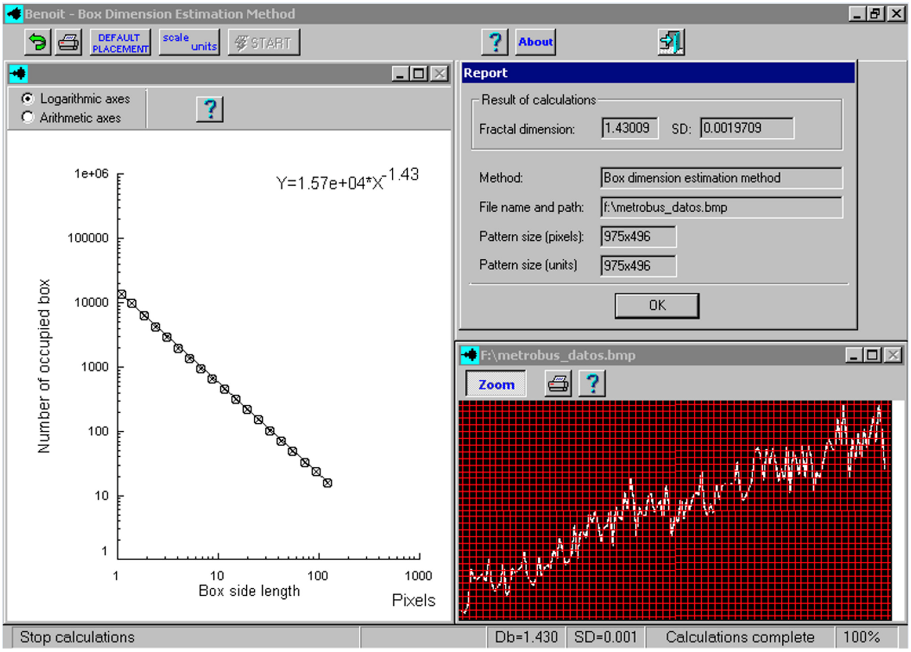

Fig. 1. Calculation of fractal dimension.

ARFIMA is a steady process with long term memory

Based on the integration parameter, ARFIMA model is generated. For ARFIMA model, a transformation is required to remove the growth or decrease, trend and periodicity of the time series with a Box-Cox of level 0.1.

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========================================
ITSM::(Maximum likelihood estimates)
========================================
Method: Maximum Likelihood
ARMA Model:
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ARMA Model:
(1-B)^{.06991}[X(t) - .8681 X(t-1) - .02606 X(t-2) - .1823 X(t-3) + .6081 X(t-4)
- .4987 X(t-5) + .2424 X(t-6) - .1104 X(t-7) + .1074 X(t-8)
- .1527 X(t-9) + .2353 X(t-10) - .3796 X(t-11) - .3743 X(t-12)
+ .5283 X(t-13)]
= Z(t) - .5389 Z(t-1) - .008898 Z(t-2) - .4969 Z(t-3)
+ .7616 Z(t-4)
WN Variance = .000000

AR Coefficients

.868140	.026059	.182339	-.608053
.498747	-.242412	.110447	-.107392
.152661	-.235265	.379611	.374306
-.528275			

MA Coefficients

-.538930	-.008898	-.496934	.761641

(Residual SS)/N = .0827473

AIC = .111000E+33

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-2Log(Likelihood) (Whittle) = .111000E+33
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Sequentially, the residuals of data series are analyzed, analyzing to what degree the model obtained is valid for the monthly influx of Metrobus users. the graph of the simple autocorrelation function (ACF) and the partial autocorrelation function (PACF) based on the inflow data is shown below (See Fig. 2).

It is observed that more than 95% of the data are within the confidence bands, therefore, the data come from an independent and identically distributed series (i.i.d). The residuals of data series should also be analyzed using the residual analysis and randomness test. The analysis is shown below.

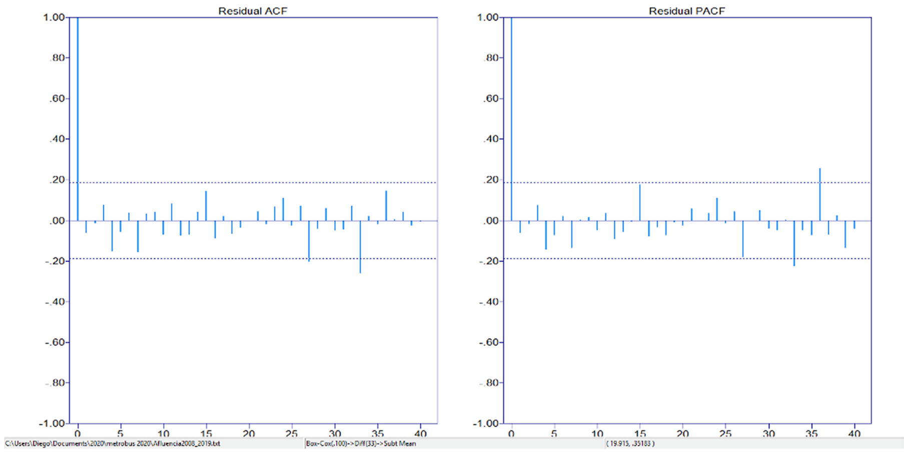

Fig. 2. ACF/PACF residuals.

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ITSM::(Tests of randomness on residuals)
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Ljung - Box statistic = 43.078 Chi-Square (20), p-value = 0.00200
McLeod - Li statistic = 23.623 Chi-Square (37), p-value = 0.95688
Turning points = 74.000~AN(72.667,sd = 4.4058), p-value = 0.76217
Diff sign points = 49.000~AN(55.000,sd = 3.0551), p-value = 0.04953
Rank test statistic = .29350E+04~AN(.30525E+04,sd = .19620E+03), p-value = .54926
Jarque-Bera test statistic (for normality) = .054737 Chi-Square (2), p-value = 0.97300
Order of Min AICC YW Model for Residuals = 0

Tests of randomness on residuals contrasts that the model passes one of the randomness tests, but by virtue of passing at least one McLeod-Li, the model can be taken as valid; this indicates that the probability of observing these data assuming that the hypothesis of the data comes from a series i.i.d. is 0.95688. It is imperative to perform the Goodness of Fit to know the behavior of the ARFIMA model to know the fit that it has throughout the time series. Figure 3 shows the inflow data versus the ARFIMA model.

Based on residuals between influx data and ARFIMA model, the goodness of fit is obtained

The Average Error (ME) (See Table 3), which indicates the approximation of the ARFIMA model based on the data. The Mean of the Absolute Value of Error (MAE) which provides the comparison of the ARFIMA model with respect to the real data. The Sum of the Error Square (SSE) and the Mean Square Error (MSE) indicate the dispersions. This reflects the separation of the ARFIMA model from its central point. The Standard Deviation of Error (SDE) which determines the average of the fluctuations of the ARFIMA model with respect to the real inflow data. The Estimate Error Bias (UM) this must be close to zero. If UM $>$ 0.2, another model must be proposed. Variability

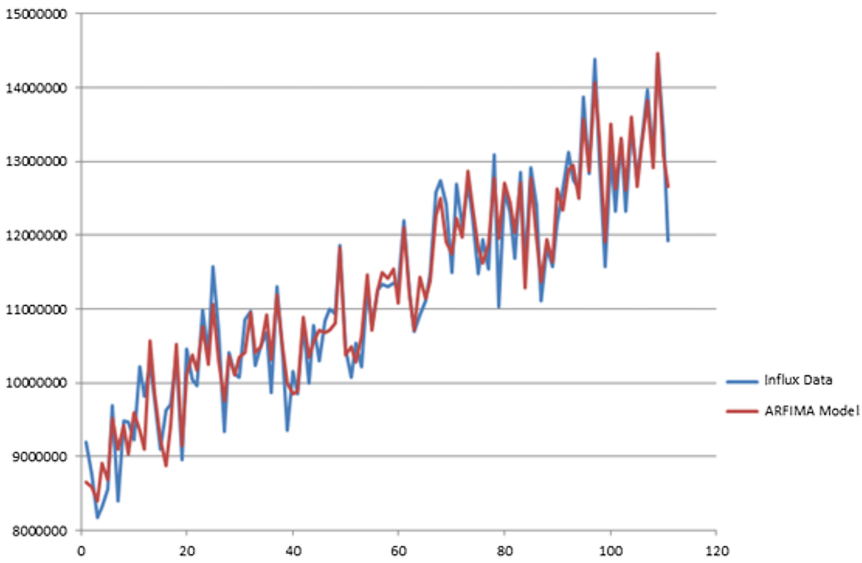

Fig. 3. Influx data versus ARFIMA model.

Model (US) shows the ability of proposed ARFIMA model to replicate variability degree against actual data flow. Variability degree is in the range from 0 to 1, with zero being the maximum variability. The non-systematic error or remaining error (UC) represents the divergence values of ARFIMA model with actual "Correlation" data. Finally, the Theil's U which is the sum of (UM) 2 + (US) 2 + (UC) 2 which compares the growths of the ARFIMA model against real influx data, using fluctuations of zero (maximum coincidence) and 1 (maximum divergence). Therefore, it has been verified based on goodness of fit, the ACF/PACF graphs and the randomness residuals test of ARFIMA model is adequate to forecast monthly influx of Metrobus Line 1 users for 2020, 2021 and 2022 years. The forecast for the monthly Influx of Metrobus Line 1 for years 2020, 2021 and 2022 in red and green in color (See Fig. 4).

4 Discussion and Results

The forecast of Mexico City Metrobus line 1 monthly influx for years 2020, 2021 and 2022 based on Fig. 4 are shown below:

It is worth mentioning that the forecast of year 2020 influx for March, April, May and June months are limited to 50%; July is calculated at 60%; August was projected at 70%; September focused on 80% of the total influx due to COVID-19 confinement and the Government restrictions.

Table 3. Goodness of fit

Goodness of fit	
ME	-1.41×10^4
MAE	2.58×10^5
SSE	1.15×10^{13}
MSE	1.04×10^{11}
SDE	3.24×10^5
Correlation Coefficient	0.9731
U	8.08×10^{-4}
U_M	1.24×10^{-3}
U_S	1.71×10^{-3}
U_C	2.84×10^{-2}

Table 4. Forecast of Mexico City Metrobus line 1 monthly influx

Forecast of Metrobus line 1 influx			
Month	Year 2020	Year 2021	Year 2022
January	11361169	13651499	13372879
February	11891641	13448016	14678055
March	13814542	14398947	14498099
April	12891010	14085587	15248697
May	12983147	14814618	15930254
June	13020088	14841871	15292412
July	13499818	15697123	16385200
August	14429980	15015049	15878766
September	13074478	13961059	14273695
October	14273703	15510534	13436573
November	13377996	14524632	13857265
December	12339324	14388168	15231780

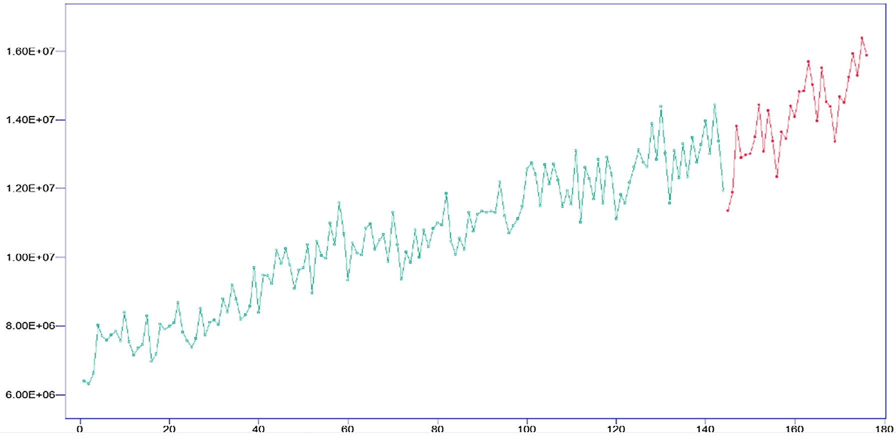

Fig. 4. Forecast of the monthly Influx of Metrobus line 1 for years 2020, 2021 and 2022. (Color figure online)

5 Conclusions

This paper has shown a forecast based on ARFIMA model in order to predict Metrobus Line 1 user's monthly influx for every month during years 2020, 2021 and 2022. Metrobus Line 1 user's influx has increased significantly year by year since its operations beginning at 2005. Influx increase give the guideline for analyzing their behavior for years 2020, 2021 and 2022 and the impact that the Increased influx will have on Metrobus line 1 infrastructure planning.

The main conclusions were the following:

a) ARFIMA model has a good performance in time series forecast, precising prediction of Metrobus line 1 user's influx, which will be necessary for infrastructure improvement plan.
b) Influx increase puts at risk healthy distance in Metrobus system, targeting as a high risk of contagion area, besides stealing and people assault, so it is necessary to control people access and program BRT unit's rides due people influx on Metrobus line 1 corridor.
c) Increase BRT units rides without a plan due users demand will affect traffic and normal life of potential users. The Mexico City Metrobus system should do an improvement plan on the unit's rides in order to attend the users demand and avoid saturation.
d) It is immediately required to review loading polygons to make a strategic planning for buses runs based on presented forecast due to Metrobus user's influx.
e) It is necessary to maintain emergency plans and make timely and accurate adjustments based on mobility collapse in Metrobus line 1 corridor.

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