# Modeling of the BFU incidence of the Panama metro line 1
# Modelado de la incidencia BFU de la línea 1 del metro de Panamá

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***Abstract*–. The objetive of this paper is modeling of the BFU incidence of the Panama metro line 1. This paper performed a group of statistical analysis like: Analysis of measures of central tendency, estimation of the characteristic equation of the data and its determination coefficient and the non-parametric Kolmogorov-Sminov test with three contrasts (normal, exponential and Weibull). This research article presents the results of the modeling of the incidence type BFU of Panama metro line 1. These results show that the incidence BFU have a exponential statistical behaviour and it has been decreasing in the 2017-2021. The results of Kolmogorov-Sminov non-parametric test show that the distribution that best fits the data of the incidences of BFU type is the exponential distribution.**

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***Keywords—Panama metro, incidents, braking button of emergency(BFU).***

***Resumen-*. El objetivo de este trabajo es modelar la incidencia del botón de frenado de emergencia de los trenes de la línea 1 del metro de Panamá. Este trabajo realizó un conjunto de análisis estadísticos como: Análisis de medidas de tendencia central, estimación de la ecuación característica de los datos y su coeficiente de determinación y la prueba no paramétrica de con tres estadísticos de contrastes (normal, exponencial y Weibull). Este artículo de investigación presenta los resultados del modelado de la incidencia tipo BFU de la línea 1 del metro de Panamá. Estos resultados muestran que la incidencia BFU tiene un comportamiento estadístico exponencial y ha ido disminuyendo en el período 2017-2021. Los resultados de la prueba no paramétrica de Kolmogorov-Sminov muestran que la distribución que mejor se ajusta a los datos de las incidencias de tipo BFU es la distribución exponencial.**

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***Palabras clave—Metro de Panamá, incidentes, botón de frenado de emergencia (BFU).***

**Digital Object Identifier (DOI):**
http://dx.doi.org/10.18687/LACCEI2022.1.1.165
**ISBN:** 978-628-95207-0-5 **ISSN:** 2414-6390

## I. INTRODUCTION

The study of the perturbations for metro line systems are important because they cause that even small perturbations propagate very quickly through the railway network, causing more delayed trains[1]–[4][5], [6][7] and it cause low quality of service for passengers waiting on railway platforms. According to Martínez *et al.,* [8] abnormally long dwelling times occur on subway lines due, in some cases, to breakdowns. These dwelling times at stations should be identified and filtered as they do not represent a normal stop at a station for the exchange of passengers. These dwelling times at stations longer than normal will be called incidents. There are numerous studies in the research literature related to these abnormally long times, which are called incidents [9][10][11][12][13][14], disturbances, safety indicators[15][16][17], failures [18], anomalies[19], disruptions [20][21][22] and accidents [23]. The scope of this paper corresponds to the study of the Bfu indicence of the Panama Metro line 1 during the period 2017-2021.

## II. DESCRIPTION OF PANAMA METRO LINE 1

Currently, the Panama Metro Network has 2 railway lines. Both railway lines 1 and 2 of the Panama Metro have a double track with a gauge of 1,435 mm [24] and right-hand traffic [25]. The track is configured as a railway line fixed directly on the viaduct. UIC54 type rails (54 Kg / m) will be used on the main road and in the Yards and Workshops [24], [25][26]. The Panamá Metro line 1 (PML1) is a metropolitan subway with subterranean and elevated track sections [1] operated with a catenary-guided transport system. It began its operations on April 6, 2014 [27][28]. Currently, the line has a length of 16 km, connecting the northern area of Panama City at the San Isidro station with the southern section of the City, to the Albrook station (Fig. 1).

This final station connects with the National Bus Terminal of Albrook that serves the overall country and the city. This station is, in addition, quite close to the local airport, Marcos A. Gelabert. At present, the headway is 3:20 minutes between 6:00 am – 8:00 am (i. e.18 train/ hour), and it is 4:30 minutes (i.e. 14 trains/hour) in off-peak hours [29].

The headway is the time distance between two successive trains on the railway track[37]. The PLM 1 dwelling time corresponds to a range between 20 to 30 seconds[38] [39]. The operating speed at the PML1 is 32 km / h [39]. The maximum speed of the metro rolling stock is 80 km / h [40]. At the southern bound, in the Albrook zone, the Panama Metro line 1 has a facility for storage and maintenance of the metro rolling stock with a surface of 10 hectares. Also, the Operations Control Center (OCC) is located at this facility. The metro rolling stock fleet includes trains with 3 and 5 electric coaches with multiple units, with a maximum capacity of 800 and 1000 passengers/train respectively [41].

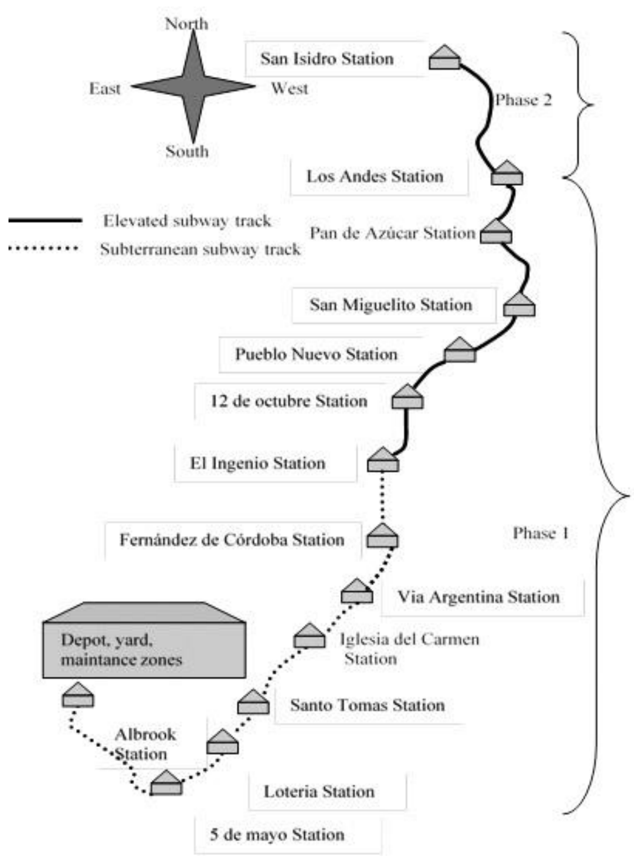


Fig. 1 Scheme of Panama Metro Line 1 (Phase 1 and Phase 2) Source: Berbey-Alvarez[30]–[36].

## III. Description of incidents of the Panama Metro line 1

For the Panama Metro, Incidents refer to indisposed users within the facilities (facilities), wagons and stations of the Panama Metro Network. It includes data on Activation of the BFU or Emergency Braking Button, Entrapments in Elevators and Stoppage Times of the Trains of Line 1 and Line 2 of the Panama Metro [42]–[46]. Of these four types of incidents, the activation of the BFU is linked to the stop times at the metro stations.

As can be seen in Table 1, the BFU incidence has been decreasing in the 2017-2021 period. In 2017, a total of 64 BFU incidences were recorded, which represents 30.62% (64/209) in a period of approximately 5 years. For the year 2021, from January to September, a total of 12 BFU-type incidents were recorded, which corresponds to 5.74% (12/209). The month with the highest number of BFU type incidences corresponds to the month of December with a total of 12.9% (27/209) in a period of 5 years, followed by the month of March with 11.48% (24/209). The month with the number of BFU incidents corresponds to the month of July with 4.78% (10/209).

**Table 1.** BFU Emergency Braking Button activations. Period 2017-2021. Panama metro line 1.

| Y/M: year/month T: Total Me: Mean | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Y/M** | **E** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **T** | **P** |
| **2017** | 7 | 5 | 5 | 5 | 6 | 5 | 6 | 4 | 4 | 4 | 4 | 9 | 64 | 5 |
| **2018** | 3 | 1 | 4 | 7 | 3 | 2 | 2 | 2 | 6 | 9 | 4 | 8 | 51 | 4 |
| **2019** | 4 | 4 | 8 | 3 | 7 | 2 | 5 | 4 | 3 | 3 | 3 | 7 | 53 | 4 |
| **2020** | 6 | 5 | 4 | 0 | 4 | 0 | 2 | 1 | 1 | 3 | 0 | 3 | 29 | 2 |
| **2021** | 0 | 0 | 3 | 0 | 2 | 1 | 4 | 1 | 1 | x | x | x | 12 | 1 |
| **T** | 20 | 15 | 24 | 15 | 22 | 10 | 19 | 12 | 15 | 19 | 11 | 27 | 209 | |
| **Me** | 4 | 3 | 5 | 3 | 4 | 2 | 4 | 2 | 3 | 5 | 3 | 7 | | |

Source: Berbey-Alvarez.

## III. Methodology

This paper developed a set of statistical analysis like: Analysis of measures of central tendency, estimation of the characteristic equation of the data and its determination coefficient and the non-parametric Kolmogorov-Sminov test with three contrasts (normal, exponential and Weibull).

The conducted research methodology is described as follows:

1. Research and statistical data collection regarding official data about the incidences in Line 1 of the Panama Metro. To do this, the research team studied the official data available in the Open Data Portal of Panama [42]–[46] (See table 1). In this paper, we select the BFU incidence over other incidences because it could has certain impact about the nominal trains services.

2. Analysis of the behaviour of BFU´s incidences during an approximate period of 5 years (2017-2021).

3. The research team did perform a central tendency analysis of the BFU´s incidence data.

4. The research team estimated what is the tendency line that best fits the absolute frequency versus intervals of BFU´s incidences.

5. Finally, the authors did perfum a Kolmogoroff-Smirnov test to determine the probability distribution that provides the best fit of BFU´s incidences for levels of confidence of 90%, 95% and 99%, respectively. This is done for normal, exponential and Weibull distributions.

## IV. Results and Discussion

### A. *Analysis of central tendency measures*

Table 2 shows central tendency measurements based on the analysis of 64 observations of BFU incidences occurred during an approximate period of 5 years. The results indicate a mean value of 3.67 BFU type incidences per month and a standard deviation of 2.38.

The asymmetry coefficient is 0.33, this is a positive or right asymmetry, indicating the existence of a cluster of values located below the mean. This means there is a higher concentration of values on the left side of the mean, with fewer values scattered on the right side.

Moreover, the coefficient of Kurtosis determines the degree of concentration of all data points in the central region of the distribution. Through the coefficient of Kurtosis, it is possible to identify the existence of a high concentration of values (Leptokurtic distribution), moderate concentration (Mesokurtic distribution) or low concentration (Platykurtic distribution). The coefficient of Kurtosis of the BFU´s incidence data is -0.44, indicating a Platykurtic distribution. It means there is a low concentration of values around the mean of 3.67. Regarding the coefficient of variation of the BFU´s incidence data, this turned out to be 65% (64.75%), indicating a high value (See table 2).

TABLE 2. Results of the analysis of central tendency measurements

| **Statistics** | **Value** |
|---|---|
| Mean | 3.67 |
| Variance | 5.65 |
| Standard deviation | 2.38 |
| Asymmetry coefficient | 0.33 |
| Kurtosis | -0.44 |
| Coefficient of variation (%) | 64.75 |
| Maximum | 9 |
| Minimum | 0 |
| Range | 9 |

**Source:** Berbey-Alvarez & Araúz

### B. *Frequency analysis of BFU´s incidence data*

Table 3 presents the analysis of frequency of occurrence of BFU´s incidences per month for the period 2017-2021 for Line 1 of the Metro of Panama. As shown, the intervals with the highest number of incidences are the ones from 2 to 3 and from 4 to 5 incidences per month, both intervals represent 23.44% (15/64) each. These two intervals are the highest of all, while the interval from 8 to 9 BFU´s incidences per month accounts for 6.25% (4/64), representing the lowest percentage.

TABLE 3. Frequency Analysis

I: interval, Af: absolute frequency, Rf: relative frequency, Rf %: percentage relative frequency, facu: cumulative frequency, freacu%: percentage cumulative relative frequency

| Interval | Af | Rf | Rf% | Facu | Freacu% |
|---|---|---|---|---|---|
| From 0 to 1 | 12 | 0.1875 | 18.75 | 12 | 18.75 |
| From 2 to 3 | 15 | 0.234375 | 23.44 | 27 | 42.19 |
| From 4 to 5 | 15 | 0.234375 | 23.44 | 42 | 65.63 |
| From 5 to 6 | 10 | 0.15625 | 15.63 | 52 | 81.25 |
| From 6 to 7 | 8 | 0.125 | 12.50 | 60 | 93.75 |
| From 8 to 9 | 4 | 0.0625 | 6.25 | 64 | 100.00 |
| | 64 | 1 | 100 | | |

**Source:** Berbey-Alvarez & Araúz

### C. *Line of tendency.*

As shown in Table 4, the best fitting line of tendency corresponds to the exponential characteristic equation This is confirmed by $R^2$. The coefficient of determination defines the percentage of the total variance accounted for by the model. The coefficient of regression, also named R-Square, determines the goodness of fit of the model. It takes on values from zero to one. As it approaches one, it indicates better model fitness. On the other hand, as the coefficient of determination approaches zero, the fitness of the model weakens, implying less robust models (see table 4).

TABLE 4. Coefficient de determination

| **Tendency** | **Characteristic equation** | **$R^2$** |
|---|---|---|
| Exponential | $y = e^{0.483x}$ | 0.8504 |
| Lineal | $y = -1.8857x + 17.267$ | 0.6813 |
| Logarithmic | $y = -4.28\ln(x) + 15.36$ | 0.4404 |
| Potential | $y = 17.025x^{-0.507}$ | 0.3167 |

Source: Berbey-Alvarez & Araúz

As shown in figure 2, the characteristic equation corresponds to exponential characteristic equation.

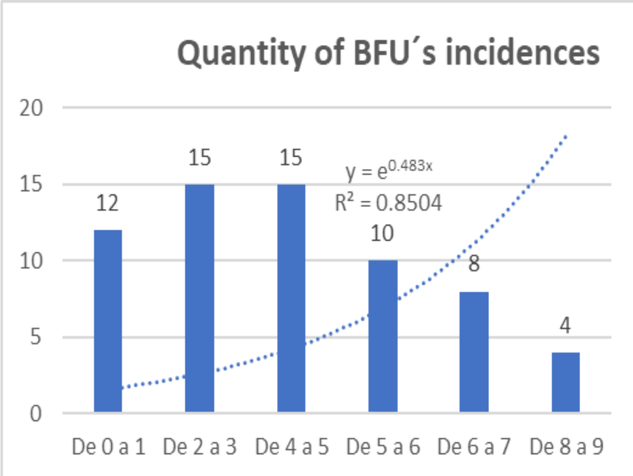


FIGURE 2. Quantity of BFU´s incidences vs. interval

### *D. Kolmogorov- Smirnov Test*

*Kolmogorov- Smirnov (KSt)* test is a nonparametric test that determines the goodness of fit of two probability distributions altogether. KSt is the máximum permisible error, if this error is not greater than the value for the null hypothesis, it is accepted. Otherwise, the null hypothesis should be rejected. The null and alternative hypothesis are:

Ho: analyzed data follows the X distribution

Ha: analyzed data does not follow the X distribution

As shown on Table 5, the maximum permissible error of the BFU´s incidence data is 0.1294 (see Table 5). The decision rule is that if the experimental test statistic (calculated value) is less or equal to the critical statistic (theoretical), the null hypothesis should be accepted, otherwise the null hypothesis should be rejected, conducting to the acceptance of the alternative hypothesis.

For the first case that shows the results of the Kolmogorov-Smirnov test (KSt), contrasting for the normal distribution, the null hypothesis is rejected at the confidence levels of 90% and 95%, in both cases the experimental test statistic is 0.1294. This test statistic value is neither less nor equal to the critical value obtained through the KSt, which is 0.1070 at the 90% confidence level, and 0.1170 at the 95% confidence level. However, the null hypothesis is accepted at the 99% confidence level, given that the experimental test statistic of 0.1294 is lower than the critical value of 0.1353.

For case 2, the results of the Kolmogorov-Smirnov test (KSt) contrasting for the exponential distribution indicate the rejection of the null hypothesis at the significance level of 90%. This is because the experimental test statistic of 0.1294 is neither less nor equal to the critical value of 0.1288. However, the null hypothesis is accepted at the significance levels of 95% and 99% given that the experimental test statistic with the value of 0.1294 is lower than the critical values of 0.1424 and 0.1702, respectively (See Table 5).

TABLE 5. Kolmogorov-Smirnov Test Results

| | | | |
|---|---|---|---|
| KsC (experimental error) | **0.1294** | | |
| **Significance level** | 0.1000 | 0.0500 | 0.0100 |
| cα( Dist Normal)[47] | 0.8190 | 0.8950 | 1.0350 |
| k(n) | 7.6524 | 7.6524 | 7.6524 |
| **Confidence level** | 0.9000 | 0.9500 | 0.9900 |
| KSt | 0.1070 | 0.1170 | 0.1353 |
| p-value | >0.1 | | |
| **Case 1: Results Dist.normal** | rejection | rejection | accepted |
| KsC (experimental error) | **0.1294** | | |
| cα( Dist exponencial) [47] | 0.9900 | 1.0940 | 1.3080 |
| k(n) | 7.6844 | 7.6844 | 7.6844 |
| **Confidence level** | 0.9000 | 0.9500 | 0.9900 |
| KSt | 0.1288 | 0.1424 | 0.1702 |
| p-value | >0.1 | | |
| **Case 2: Results Dist.exponencial** | rejection | accepted | accepted |
| KsC (experimental error) | **0.1294** | | |
| **Significance level** | 0.1000 | 0.0500 | 0.0100 |
| cα( Dist Weibull) [47] | 0.8030 | 0.8740 | 1.0070 |
| k(n) | 7.5498 | 7.5498 | 7.5498 |
| **Confidence level** | 0.9000 | 0.9500 | 0.9900 |
| KSt | 0.1064 | 0.1158 | 0.1334 |
| p-value | >0.1 | | |
| **Case 3: Results Dist.Weibull** | rejection | rejection | accepted |

Source: Berbey-Alvarez & Araúz

Case 3 presents the results of the Kolmogorov-Smirnov test contrasting for the Weibull distribution. In this case, the null hypothesis is rejected at the significance levels of 90% and 95% because the experimental test statistic of 0.1294 is neither less nor equal to the critical values of 0.1064 at the 90% and 0.1158 at the 95%, respectively. However, the null hypothesis is accepted at the 99% significance level because the experimental test statistic of 0.1294 es lower than the critical value of 0.1334.

As shown on Table 5, the exponential distribution is the one that best fits the model that analyzes the BFU incidences, at the 95% and 99% confidence levels.

## CONCLUSIONS

It is important the study of the perturbations for metro line systems because it affects the quality of service for users waiting on railway platforms. They cause that even small deviations or perturbations propagate quickly through the railway network, causing more delayed trains and it causes low quality of service for passengers waiting on railway platforms. In this paper, we select the BFU incidence over other incidences because it could be a impact about the nominal trains services.

In general, the BFU incidence has been decreasing in the 2017-2021 period by the Panama metro line1. The trend line that best fits the BFU absolute frequency vs. interval graph corresponds to a characteristic equation of exponential distribution. According to the results of Kolmogorov-Sminov non-parametric test, the distribution that best fits the data of the incidences of BFU type corresponds to an exponential distribution for the 95% and 99% confidence levels, respectively. Preliminary, the implications of this study corresponds to its potential impact of the delays times on the nominal trains services.

## ACKNOWLEDGMENTS

The authors greatly appreciate Metro of Panama for sharing statistical data of its operations in the Open Data Portal of Panama. Additionally, our thanks to *"Universidad Tecnológica de Panamá*", specifically "*Centro de Investigación e Innovación Eléctrica, Mecánica y de la Industria (CINEMI)"* and the School of Industrial Engineering for their support throughout this research.

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