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TRAFFIC ENGINEERING INDICATORS ANALYSIS AS EXPLANATORY VARIABLES OF TRAFFIC NOISE

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Abstract
Improve models for predicting traffic noise is a constant demand in order to have tools increasingly accurate. Usually, the independent variables most commonly used are vehicle flow, average speed and distance from the source. However, there have been constantly situations with peculiar behavior of traffic in large urban centers: the queues in peak hour. In this context, this study aims to evaluate a specific parameter of traffic engineering (saturation degree) as a possible independent variable for prediction models of traffic noise. This parameter indicates the use of road capacity and if there is over demand. This research is part of a doctoral thesis at the Federal University of Rio de Janeiro, Brazil.
Keywords: Traffic Noise, Saturation Flow Rate.

1 Introduction

The growth of vehicular traffic in urban areas brings a series of problems and drawbacks, which engineer tries to solve and predict [1]. Especially with regard to noise generation have been a sought for equations and relations between the expected volume of traffic and the noise levels produced [2] [3] [4] [5] [6].
Among the various models currently found in the technical means there is ample use of the volume of vehicles from the road as the main parameter for prediction of noise generation. However, this value is not able to present a complete picture of the generation of noise between one place and another, since the flow capacity of the roads is different and therefore an important avenue has greater potential to impact than a small street.
In traffic engineering, a very usual relationship, which reflects somewhat the capacity utilization of the lanes, is the saturation degree. This parameter relates primarily to traffic demand in terms of volume of vehicles with the capacity of the lanes in the stretch under consideration. The same can often indicate if the route runs close to capacity, which directly implies the formation of queues, low speed, high density of vehicular traffic, among others.

In this context, the attempt to insert this parameter as an independent variable in a predictive model of noise is, as far as we know, unprecedented. It is believed that there may be a relationship between noise levels and the degree of saturation of a way due to the fact that a high value for this parameter may indicate a significant volume of traffic. On the other hand, can also indicate a low capacity of the lanes, but whatever the situation, the operation of the traffic is impaired, which may contribute to increased noise emission.
According to common sense "empty" roads produce less noise that clogged roads, i.e., roads with lower saturation degree produce less noise than roads close to saturation. This paper wants to determine whether there is any relationship between these two parameters: Saturation Degree and noise generation, denying or confirming common sense, which in this case would result in the possibility of future development of models that best describe this relationship.

2 Methodology

The noise measurements were conducted in accordance with the recommendations prescribed by NBR 10151 [7]. The meter sound pressure level was at the height of 1.20 m from the ground and at least 1.50 m away from walls and / or surfaces that might reflect some form of sound waves. This technique was used as a reference once it is a standard for urban noise measure in Brazil. It is worth noting that the requirements of this Brazilian Standard are quite similar to International Standards, such as the ISO11819-1 *"Acoustics - Method for Measuring the Influence of road surfaces on traffic noise"*.
For carrying out the research there were chosen two significant traffic corridors in the city of Belo Horizonte: Av. Amazonas in two different sites and Av. Dom Pedro II. This route has two lanes in each direction, while another one has three lanes, both routes operating in dual carriages with central reservation separating them.
Measurements were made on typical weekdays segregated into two periods: morning peak and afternoon peak.
To perform the noise measurements it was used a meter sound pressure level type 2 brand Extech and model 407780. The equipment, which has 1.5 dB of accuracy, was programmed to collect data in "Fast" model every second, using the weighting curve "A", according to recommendations of the NBR 10151 [2]. It was used the protective foam on the microphone to minimize wind effects in the measurement site. The equipment was calibrated before and after each measurement at the frequency of 1000 Hz with the sound pressure level equal to 94 dB to ensure accuracy of data collected at each point. The calibrator used is the same brand and has an accuracy of plus or minus 0.5 dB.
Measurements were grouped into periods of 15 minutes. For each of these intervals will be obtained with the specific software of the equipment, the following parameters:

- Equivalent sound level (Leq – equation (1));
- Maximum value;
- Minimum value;
- Percentis levels (Ln).

$$L_{eq} = 10.\log \frac{1}{T}\int_0^T \frac{P^2(t)}{P_0^2}dt \qquad (1)$$

Where:

- T is time integration;
- P_T is the acoustic power;
- P_0 is the reference acoustic power;
- L_{eq} is Equivalent sound level in dB(A).

In the present study was not considered the influence of meteorological variables, such as air velocity and temperature. Although these parameters have influence, it is believed that their contributions are relatively small in the overall effect of noise, before other independent variables considered.
To determine the saturation degree were held simultaneously the Classified Vehicular Count and the noise measurements. That count where performed by totalizing the vehicles by utilized mode; the noise measurement were made in the same section as the Classified Count. The values found in the Classified Count were divided by the capacity of the runway, considered as 1800 phv (peak-hour vehicle).

3 Results and Discussions

3.1 Initial considerations

Preliminarily, as expected, it can be seen in Figure 2 that there is a trend of increasing noise with increasing vehicle flow.

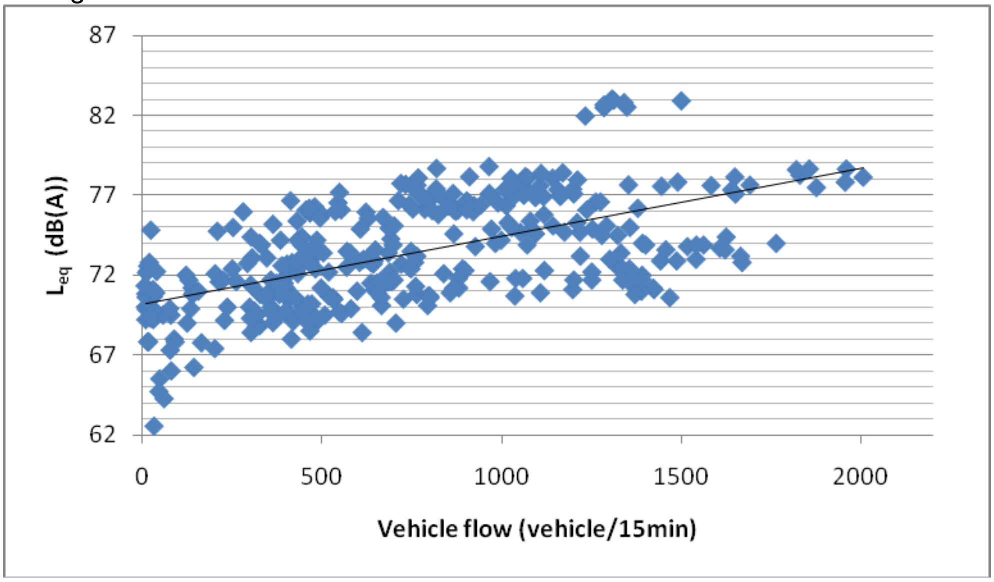

Figure 2 - Lattice dispersion of data points

Since the purpose of this study is to evaluate the relationship between noise and a traffic performance indicator, Figure 3 below lists two basic variables of traffic engineering that somehow supports the proposal of this work. That is, there is an inverse correlation between saturation degree and average speed. The greater the saturation degree, the lowest is the average speed. This allows us to infer that for very high flow values near the lane capability, the average speed drops significantly, which may have direct implications on traffic noise.

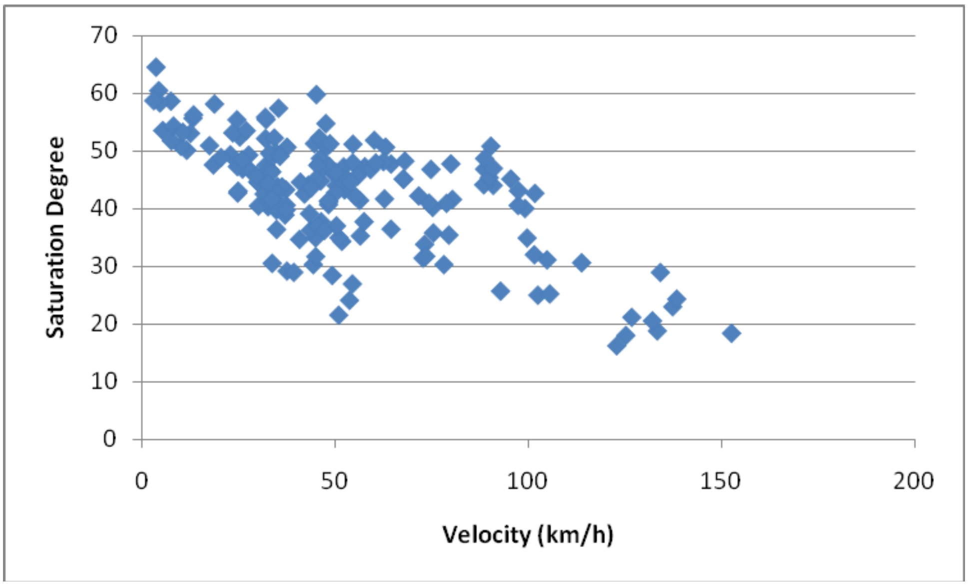

Figure 3 - Relationship between saturation degree and operating speed

3.2 Noise and saturation flow rate relation analysis

Applying the statistical software *SPSS*, aiming to identify the trend between noise levels and saturation degree, it was obtained the graphs illustrated in Figures 4, 5 and 6 respectively to the points of Av. Amazonas 1, 2 and Av. Pedro II.

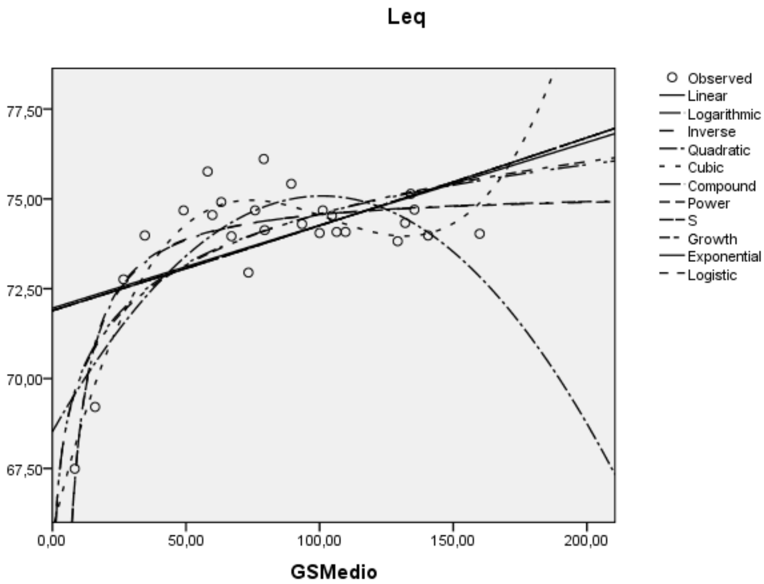

Figure 4 - Relationship between Saturation Degree and Leq - Av Amazonas 1

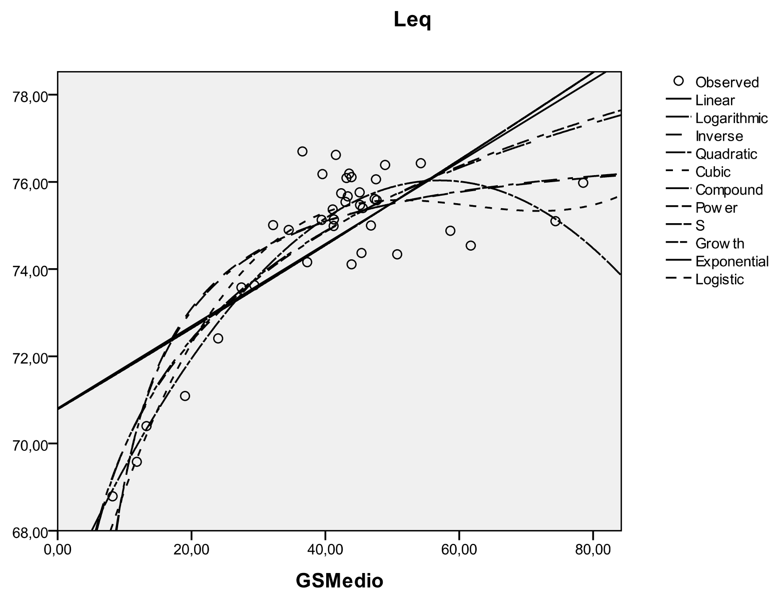

Figure 5 - Relationship between Saturation Degree and Leq - Av Amazonas 2

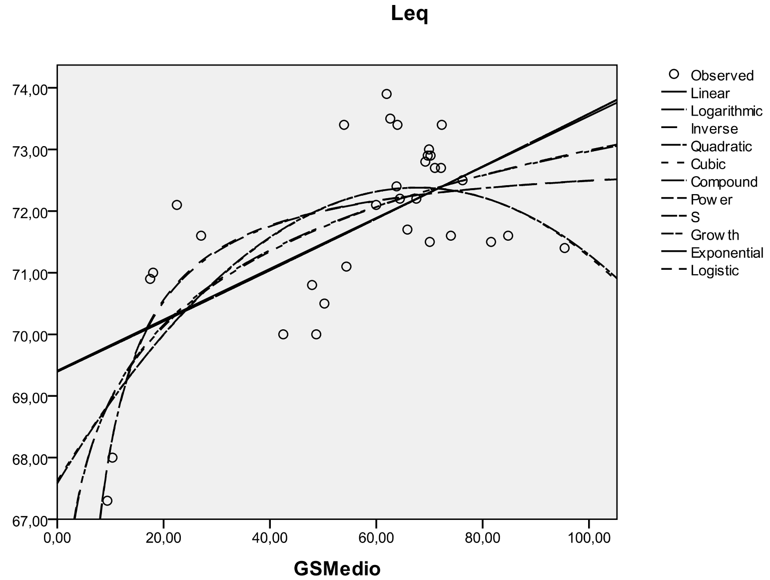

Figure 6 - Relationship between Saturation Degree and Leq - Av. Pedro II

It were tested 11 different trends, namely:

- S-curve. Model whose equation is $Y = e^{(b_0 + (\frac{b_1}{t}))}$;
- Linear. Model whose equation is $Y = b_0 + (b_1.t)$;
- Logarithmic. Model whose equation is $Y = b_0 + (b_1.\ln(t))$;
- Inverse. Model whose equation is $Y = b_0 + (b_1 / t)$;
- Quadratic. Model whose equation is $Y = b_0 + (b_1.t) + (b_2.\ t^2)$;
- Cubic. Model that is defined by the equation $Y = b_0 + (b_1.t) + (b_2.t^2) + (b_3.t^3)$;
- Power. Model whose equation is $Y = b_0 .(t^{b_1})$;
- Compound. Model whose equation is $Y = b0.(b_1^{\ t})$;

- Logistic. Model whose equation is $Y = 1 \frac{1}{(1/u + (b_0 . (b_1^{t})))}$ where u is the upper boundary value;
- Growth. Model whose equation is $Y = e^{(b_0 + (b_1 . t))}$;
- Exponential. Model whose equation is $Y = b_0 . (e^{(b_1 * t)})$ where Y is the dependent variable (Leq), b0, b1 ,..., bn are the coefficients, t is the independent variable.

Among all the options evaluated, the best correlations were obtained for the cubic, S and quadratic cruve, as can be seen in Tables 1, 2 and 3 respectively to the points of Av. Amazonas n° 1, n°2 and Av. Pedro II.

Table 1 - Summary Av. Amazonas n°1

Model Summary and Parameter Estimates

Dependent Variable:Leq

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	,260	8,427	1	24	,008	71,959	,023		
Logarithmic	,579	33,052	1	24	,000	65,427	1,987		
Inverse	,790	90,302	1	24	,000	75,244	-68,218		
Quadratic	,656	21,896	2	23	,000	68,519	,130	,000	
Cubic	,816	32,628	3	22	,000	65,753	,305	-,003	1,037E-5
Compound	,263	8,581	1	24	,007	71,891	1,000		
Power	,586	33,968	1	24	,000	65,601	,028		
S	,801	96,624	1	24	,000	4,321	-,958		
Growth	,263	8,581	1	24	,007	4,275	,000		
Exponential	,263	8,581	1	24	,007	71,891	,000		
Logistic	,263	8,581	1	24	,007	,014	1,000		

The independent variable is GSMedio.

Table 2 - Summary Av. Amazonas n°2

Model Summary and Parameter Estimates

Dependent Variable:Leq

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	,516	39,436	1	37	,000	70,805	,094		
Logarithmic	,747	109,198	1	37	,000	61,682	3,576		
Inverse	,788	137,250	1	37	,000	77,103	-80,133		
Quadratic	,833	89,747	2	36	,000	66,352	,339	-,003	
Cubic	,861	72,075	3	35	,000	63,843	,603	-,010	5,468E-5
Compound	,519	39,930	1	37	,000	70,785	1,001		
Power	,754	113,337	1	37	,000	62,430	,049		
S	,798	146,467	1	37	,000	4,346	-1,105		
Growth	,519	39,930	1	37	,000	4,260	,001		
Exponential	,519	39,930	1	37	,000	70,785	,001		
Logistic	,519	39,930	1	37	,000	,014	,999		

The independent variable is GSMedio.

Table 3 - Summary Av. Pedro II

Model Summary and Parameter Estimates

Dependent Variable:Leq

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	,381	19,055	1	31	,000	69,412	,041		
Logarithmic	,494	30,253	1	31	,000	64,912	1,749		
Inverse	,566	40,472	1	31	,000	72,974	-48,344		
Quadratic	,513	15,771	2	30	,000	67,581	,142	-,001	
Cubic	,513	10,164	3	29	,000	67,621	,138	,000	-5,147E-7
Compound	,384	19,350	1	31	,000	69,395	1,001		
Power	,500	31,010	1	31	,000	65,094	,025		
S	,576	42,115	1	31	,000	4,290	-,688		
Growth	,384	19,350	1	31	,000	4,240	,001		
Exponential	,384	19,350	1	31	,000	69,395	,001		
Logistic	,384	19,350	1	31	,000	,014	,999		

The independent variable is GSMedio.

About the point 1 of Av Amazonas, it appears that despite the higher R^2 (0.816) was obtained for the cubic curve, the curve of type S also had a significant R^2 (0.801) and a much higher value for F test. Identical behavior was found in another section of this avenue. To the point of Av Pedro II, even with average values lower than those observed for Av Amazonas, the largest coefficient of determination R^2 was observed for the S curve, yet having the greatest value for F test.

Also concerning the previous tables, it appears that all the curves tested had excellent rates of significance, as can be verified by the column *Sig*.

When the analysis is made for the points together, the R^2 falls. This was expected since there are a number of other peculiarities of each point which also influences the noise. However, the findings obtained for all items are kept in isolation, that is, the curve of type S showed the highest rate (R^2 and F test), compared to the cubic and quadratic trends. Figure 5 shows the graph obtained by the software and Table 4 presents the results of the statistical tests.

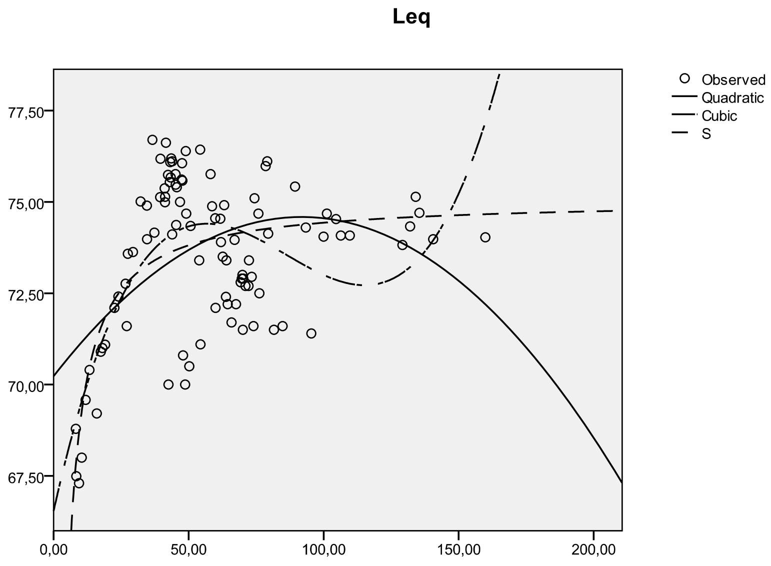

Figure 5 - Regression of all data points

Table 4 - Regression of all data points

Model Summary and Parameter Estimates

Dependent Variable:Leq

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Quadratic	,198	11,722	2	95	,000	70,231	,095	,000	
Cubic	,388	19,834	3	94	,000	66,543	,331	-,004	1,689E-5
S	,401	64,263	1	96	,000	4,318	-,834		

The independent variable is GSMedio.

3.3 Results discussions

In all tests, there are some behaviors that were expected depending on the objectives of this work. That is, the relationship between noise and saturation degree is not linear, i.e., the first does not increase indefinitely according to the second.

From the database collected it was found that for high values of saturation degree there is a tendency to stabilize the noise or even to decrease. This happens because in forced flow, the volume of traffic and the average speed in a section decreases significantly. Since there is an optimal density for which there is a maximum traffic flow, it can be concluded that due to the slowing down observed from this point the noise generated by vehicles tends to stabilize or even decrease, followed by slowing average. With this we can infer that already settled thoughts like "*the noise is greater as the traffic increase*" are only valid with respect to the traffic capacity the route may let pass, not the real flow demand. In other words, a large number of congested vehicles deliver the same or even less noise than a smaller number of vehicles traveling at free flow.

With regard to the behavior of noise depending on the saturation degree of a given route, the database of this study was insufficient to exactly infer which is the best fitting curve, since three curves that were more precise, *a priori*, were logical and satisfactory results. However, even with some degree of uncertainty, it was found that the behavior is nonlinear and S-type curve was the one that showed greater adherence to the mesh of points. This presents a behavior in which the noise stabilizes for higher values of saturation degree. Finally, it is important to note that roads with equal saturation degree and with different capabilities, will also have different noise levels. That is, routes with more capacity will only have high degrees of saturation for a greater flow than routes with less capacity. So, the number of sources (vehicles) in the process with greater capacity will be greater than in the process with a limited capability to generate the same saturation degree. Thus, there was a final assessment is to consider the saturation degree multiplied by the number of tracks on each point and its relationship to the curves analyzed, as can be seen in Figure 7 and Table 5.

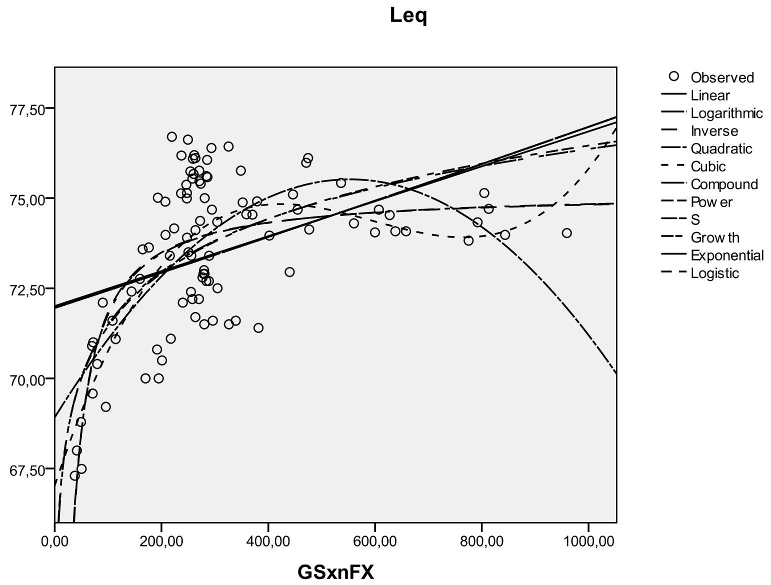

Figure 7 - Correlation between Degree of Saturation times number of tracks and Leq

Table 5 - Correlation between Degree of Saturation times number of tracks and Leq

Model Summary and Parameter Estimates

Dependent Variable:Leq

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	,179	20,974	1	96	,000	72,006	,005		
Logarithmic	,406	65,613	1	96	,000	61,758	2,114		
Inverse	,499	95,717	1	96	,000	75,150	-332,014		
Quadratic	,427	35,328	2	95	,000	68,916	,024	-2,161E-5	
Cubic	,499	31,264	3	94	,000	67,023	,045	-8,274E-5	4,636E-8
Compound	,183	21,499	1	96	,000	71,955	1,000		
Power	,415	68,072	1	96	,000	62,381	,029		
S	,513	101,082	1	96	,000	4,320	-4,638		
Growth	,183	21,499	1	96	,000	4,276	6,744E-5		
Exponential	,183	21,499	1	96	,000	71,955	6,744E-5		
Logistic	,183	21,499	1	96	,000	,014	1,000		

The independent variable is GSxnFX.

What is happening is that the coefficient of statistic determination R^2 increases for all curves and in particular for having delivered the best indicators (S curve) the increase was about 28%, a significant increase.

4 Conclusions

The analysis in this study showed that the noise increases proportionally to the flow of traffic, but not indefinitely. However, traffic flow is highest when the density of vehicles on the track is optimal. After this value, the flow begins to decrease, even with a large number of vehicles wanting to pass. At this moment the formation of queues (congestion) initiates and a decrease in speed happens. A parameter that can indicate this situation is the saturation degree. By correlating the noise with this parameter it is clear that it has a behavior similar to an S-type curve. This curve is practically constant after a certain value, in this case, high saturation degree.

In other words, the major conclusion of this work is that a congested road can emit less noise than a route that have low-volume vehicles. This is mainly due to the fact that in a congested route, the flow speed is very low, whereas in free flow, it increases significantly. Finally, it is recommended that more studies be done in the area as a way to identify the influences of the operation of traffic noise levels, because these conclusions makes it easy to develop plans to minimize noise pollution in urban centers more efficient.

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