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SIMULATIONS OF DIFFERENT CONFIGURATION OF MODAL SPLIT: IMPACTS ON TRAFFIC NOISE IN UR-BAN CENTERS

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Noise pollution in urban areas is directly linked to the traffic flow on roads and the types of vehicles, as well as several other independent variables. However, today is not possible to infer with certainty what would be the impacts on noise levels in urban centers, from a successful action to encourage the use of buses rather than cars, that is, a collective mode instead of an individual one. Thus, the objective of this study was to apply a developed methodology and, in this way, to identify what would be the impacts that changes in the current configuration on operation of transport systems (demand and supply), and the modal split of passenger transport in urban centers, would result in noise levels emitted focused in transfer of automobile and motorcycle users to buses. The main conclusion was that efforts to minimize noise through the management of mobility should be made well planned, and even that, may not be effective.

1. Introduction

Concerns about the environmental impacts of human activities have been increasing throughout the world. With regard to urban centers, traffic vehicle is a potent contributor to three specific types of pollution: air, noise and visual (Rodrigues, 2006).

With regard to noise pollution, vehicular fleet has different capabilities of noise emission. In a recent study done by Can et al. (2008) has shown that the relationship between sound power from passengers cars and light trucks is equal to 9.12. This is, a heavy vehicle is capable of producing 9.12 times more noise than a light vehicle, taking into account the behavior of logarithmic decibel scale.

When making an assessment of noise generated by each of these modes, as compared with the total of persons carried by them, we arrive at a noise output per person reverse, with respect to modes of transportation noisier. That is, the car (minor sound power) emits more noise per person than the bus (higher sound power). When considering occupations averages of cars and buses at peak hour urban centers as being, respectively, 1.5 and 70 passengers, it appears that output per - person is around 65 dB for buses, while for cars the figure is around 73 dB (RODRIGUES et al., 2008b).

From these statements, it is a question that guides this paper: *" Might we then reduce the noise levels present in urban centers, in particular, Brazilians, from changes in passenger modal split, primarily among the cars and buses?"*.

2. Methodology

To accomplish the proposed goal, showed in the previous section, it was used a statistical prediction traffic noise model, calibrated specifically to do simulations the simulation of changes in passenger modal split of transport in urban centers, using the SPSS software.

2.1 Local Data Collection

The points to collect data were chosen a priori focused in avenues with large capacity and traffic demand that comprise the main road system of the city of Belo Horizonte-MG, Brazil, with different features. In addition, we selected two additional points to make atypical situations, i.e., a road with high average speed and a low-speed traffic flow and less significant. A total of 11 points from six different avenues were measured.

2.2 Noise Measurements

The noise measurements were conducted in accordance with the recommendations prescribed by the Brazilian standard NBR 10.151 (ABNT, 2000). It is known that the requirements of this standard are very similar to the International Standards ISO11819-1 "Acoustics - Method for measuring the Influence of road surfaces on traffic noise."

The measurements were carried out in the morning (5:00 to 10:00 a.m.) and afternoon (16:00 to 21:00 a.m.) and for each of these intervals were obtained with the specific software of the equipment, the following indicators:

- Equivalent Sound Level (Leq);
- Maximum value observed;
- Minimum value observed;
- Levels Percentiles (Ln).

The level meter sound pressure used was a model of the brand Extech, model 407780. The calibrator used was from the same brand and has accuracy of ± 0.5 dB.

2.3 Data Collection for Passenger Vehicle

To do simulations on the modal split change, it was necessary to measure the average number of people per vehicle (bus, car, motorcycle, etc.) and, thus, whether there is idleness on the transport system that can be further explored through a reorganization of relationship between supply and demand.

2.4 Model Calibration

To perform simulations on modal split changes, and identify the impacts on noise levels, it was used a prediction model calibrated with the aid of the software SPSS Statistics 17.0.

To verify the significance of the statistical model, were used as validation parameters the coefficient of determination R2 statistics, standard error of estimation, testing "F" and " T-Student", the comparison between the residuals of each estimate and frequency analysis of estimate errors.

All these data were easily obtained from the output data of the software, as illustrated in Figure 1.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,908[a]	,825	,819	1,36188	,825	137,899	10	292	,000

a. Predictors: (Constant), HierarquiaViaria, DistMedCentroVia, LnBusAD, LNVelocidAD, LnPercentPesado, LnBUSOP, LnVelocidOP, LnMotoTotal, LnAutoAD, LnAutoOP

b. Dependent Variable: Leq

Figure 1. Illustration of the outputs data from SPSS

2.5 Simulations of Changes in Modal Split of Passenger Transport

The calibrated model was applied to hypothetical situations. That is, from the findings of idleness on the transport system, it was applied this value through configuration modal split changes in order to identify the decrease in the number of vehicles and this interference on noise levels.

This application was made by the results obtained with data collection, using the idleness capacity on identified modes of transport through a rearrangement of the number of vehicles, as well as the present modal split, in order to keep constant the number of persons carried out.

3. Presentation of Results

3.1 Noise Levels

Preliminarily, Figure 2 shows the variation on Leq during the research period. It can be seen that the noise is lower at dawn and then increase, remaining constant during the whole day, whether in peak hours, either in between peaks. After 8:00 p.m. is verified again a declining trend.

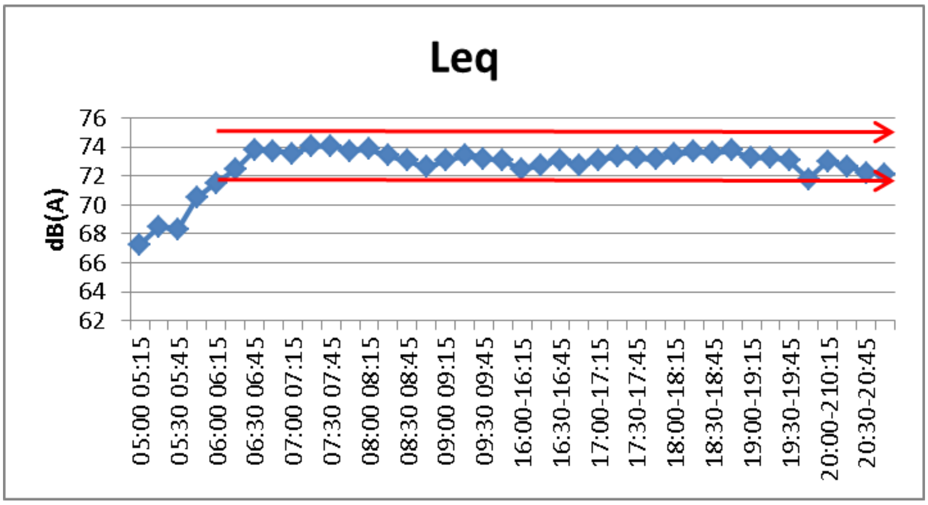


Figure 2: Variations in Leq dB(A) on measured points

3.2 Relationship between supply and demand of the transport system

The Figures below (3 and 4) present the average results of occupation identified for the various transportation modes measured. From them it can be concluded that there is idle capacity on the transport system, which one can be better utilized.

The blue data is the period during the morning and the red data is from the afternoon. *B>C* is the traffic flow from residential areas to the center of the city and *C>B* is the opposite. *Geral* is the general average form the values.

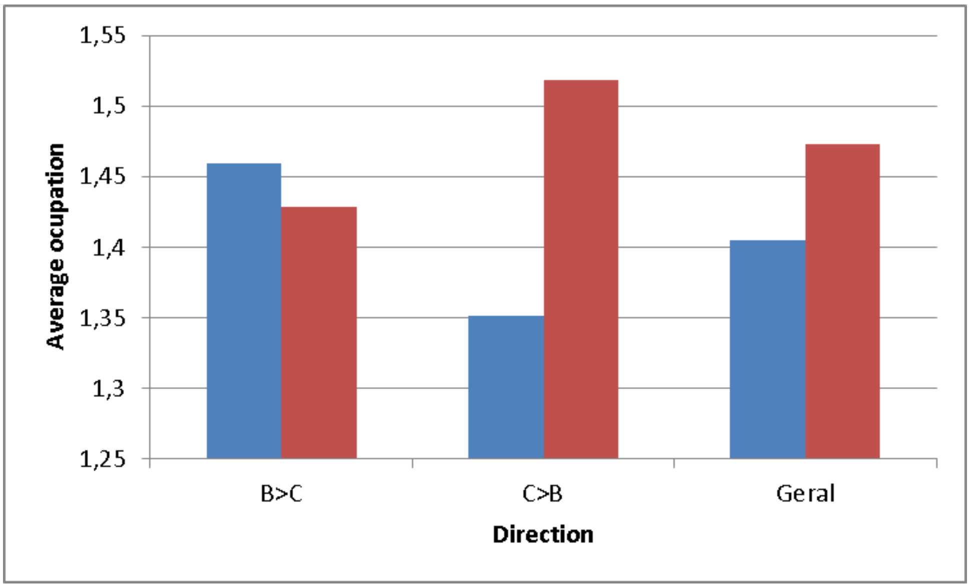


Figure 3: Summary of variation in the average occupancy of cars

From the previous figure it is concluded that, overall, the average occupancy of cars is 5% higher in afternoon than in the morning, with low values on both periods.

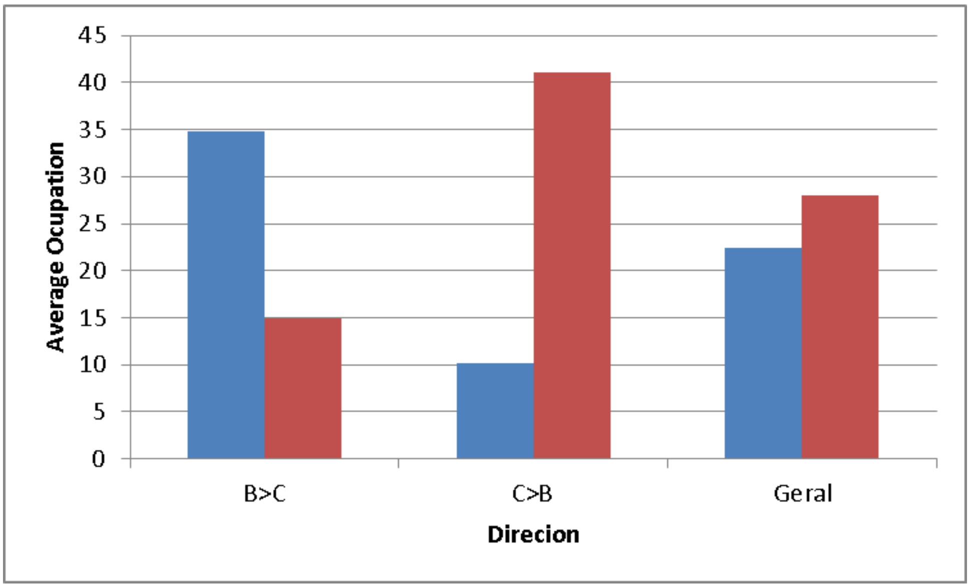


Figure 4: Summary of variation in the average occupancy of buses

From the previous Figure, it appears that the average occupancy of buses in the afternoon is 25% higher than in the morning. Importantly, the data presented include hour peak and hours out of the peak, which explains the relatively low values of average occupancy collected (Figure 5).

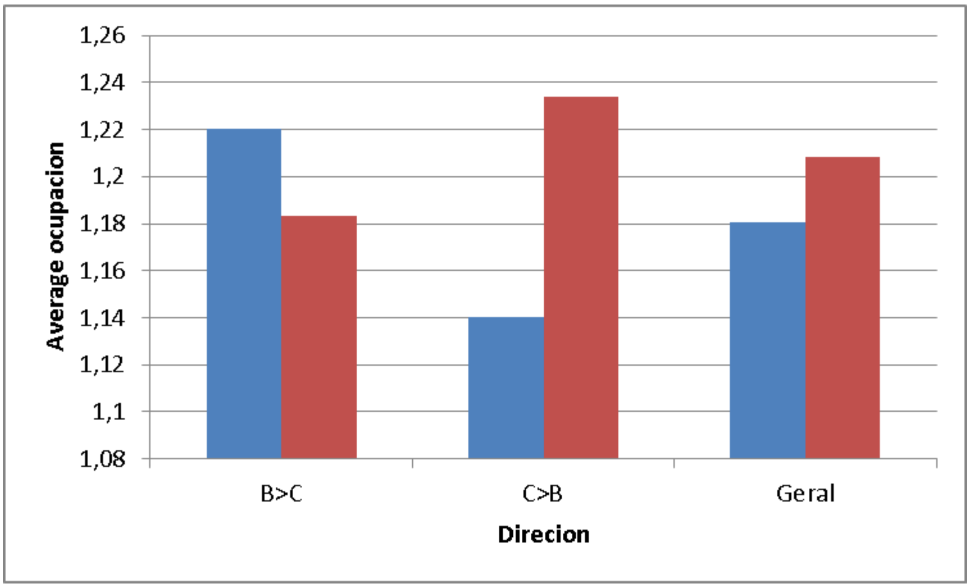


Figure 5: Summary of variation in the average occupancy of the motorcycles

From the previous Figure, it appears that the motorcycle average occupancy in the afternoon is 2.5% higher than in the morning.

Analyzing the relationship (average) between demand and capacity of the transportation system (auto, bus and motorcycle), it appears that, in general, there is idle capacity (around 25% in the highest peak), as can be seen on Figure 6.

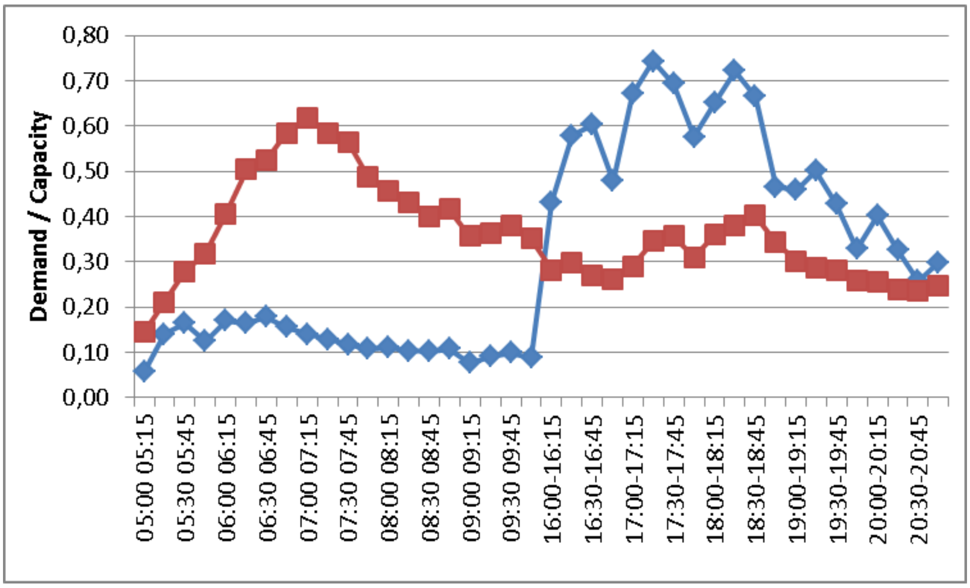
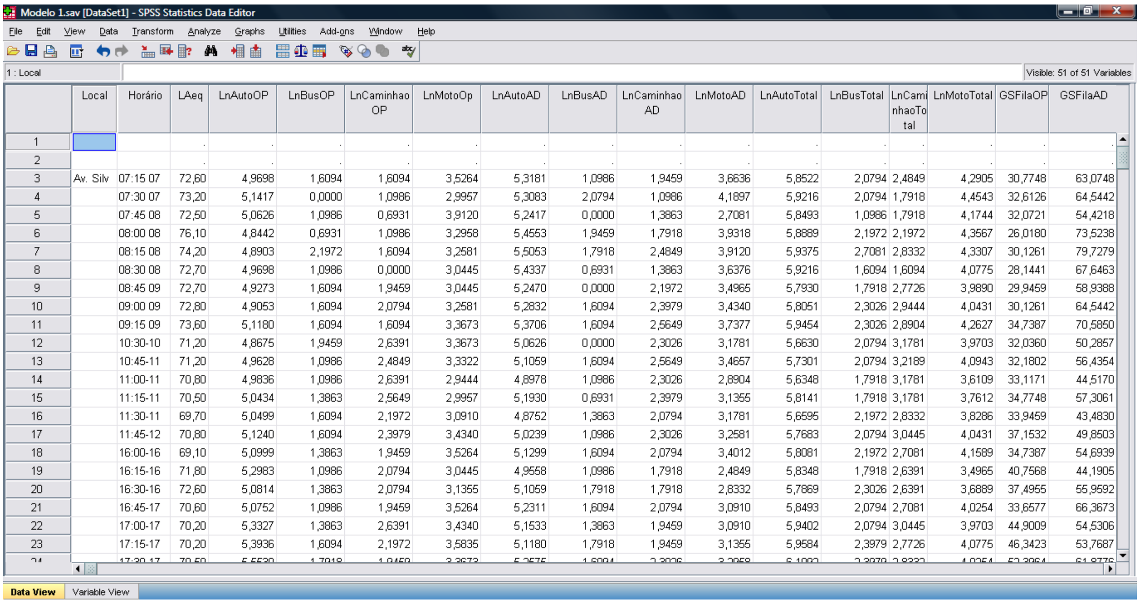


Figure 6: Variation of the relationship between demand and system capacity

3.3 Noise Prediction Model

As mentioned, a model was calibrated with the aid of SPSS software specifically to perform simulations on modal split changes. The Figure 7 illustrates the insertion of data in such software.



	Local	Horário	LAeq	LnAutoOP	LnBusOP	LnCaminhaoOP	LnMotoOp	LnAutoAD	LnBusAD	LnCaminhaoAD	LnMotoAD	LnAutoTotal	LnBusTotal	LnCaminhaoTotal	LnMotoTotal	GSFilaOP	GSFilaAD
1			.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
2			.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3	Av. Silv	07:15 07	72,60	4,9698	1,6094	1,6094	3,5264	5,3181	1,0986	1,9459	3,6636	5,8522	2,0794	2,4849	4,2905	30,7748	63,0748
4		07:30 07	73,20	5,1417	0,0000	1,0986	2,9957	5,3083	2,0794	1,0986	4,1897	5,9216	2,0794	1,7918	4,4543	32,6126	64,5442
5		07:45 08	72,50	5,0626	1,0986	0,6931	3,9120	5,2417	0,0000	1,3863	2,7081	5,8493	1,0986	1,7918	4,1744	32,0721	54,4218
6		08:00 08	76,10	4,8442	0,6931	1,0986	3,2958	5,4553	1,9459	1,7918	3,9318	5,8889	2,1972	2,1972	4,3567	26,0180	73,5238
7		08:15 08	74,20	4,8903	2,1972	1,6094	3,2581	5,5053	1,7918	2,4849	3,9120	5,9375	2,7081	2,8332	4,3307	30,1261	79,7279
8		08:30 08	72,70	4,9698	1,0986	0,0000	3,0445	5,4337	0,6931	1,3863	3,6376	5,9216	1,6094	1,6094	4,0775	28,1441	67,6463
9		08:45 09	72,70	4,9273	1,6094	1,9459	3,0445	5,2470	0,0000	2,1972	3,4965	5,7930	1,7918	2,7726	3,9890	29,9459	58,9388
10		09:00 09	72,80	4,9053	1,6094	2,0794	3,2581	5,2832	1,6094	2,3979	3,4340	5,8051	2,3026	2,9444	4,0431	30,1261	64,5442
11		09:15 09	73,60	5,1180	1,6094	1,6094	3,3673	5,3706	1,6094	2,5649	3,7377	5,9454	2,3026	2,8904	4,2627	34,7387	70,5850
12		10:30-10	71,20	4,8675	1,9459	2,6391	3,3673	5,0626	0,0000	2,3026	3,1781	5,6630	2,0794	3,1781	3,9703	32,0360	50,2857
13		10:45-11	71,20	4,9628	1,0986	2,4849	3,3322	5,1059	1,6094	2,5649	3,4657	5,7301	2,0794	3,2189	4,0943	32,1802	56,4354
14		11:00-11	70,80	4,9836	1,0986	2,6391	2,9444	4,8978	1,0986	2,3026	2,8904	5,6348	1,7918	3,1781	3,6109	33,1171	44,5170
15		11:15-11	70,50	5,0434	1,3863	2,5649	2,9957	5,1930	0,6931	2,3979	3,1355	5,8141	1,7918	3,1781	3,7612	34,7748	57,3061
16		11:30-11	69,70	5,0499	1,6094	2,1972	3,0910	4,8752	1,3863	2,0794	3,1781	5,6595	2,1972	2,8332	3,8286	33,9459	43,4830
17		11:45-12	70,80	5,1240	1,6094	2,3979	3,4340	5,0239	1,0986	2,3026	3,2581	5,7683	2,0794	3,0445	4,0431	37,1532	49,8503
18		16:00-16	69,10	5,0999	1,3863	1,9459	3,5264	5,1299	1,6094	2,0794	3,4012	5,8081	2,1972	2,7081	4,1589	34,7387	54,6939
19		16:15-16	71,80	5,2983	1,0986	2,0794	3,0445	4,9558	1,0986	1,7918	2,4849	5,8348	1,7918	2,6391	3,4965	40,7568	44,1905
20		16:30-16	72,60	5,0814	1,3863	2,0794	3,1355	5,1059	1,7918	1,7918	2,8332	5,7869	2,3026	2,6391	3,6889	37,4955	55,9592
21		16:45-17	70,60	5,0752	1,0986	1,9459	3,5264	5,2311	1,6094	2,0794	3,0910	5,8493	2,0794	2,7081	4,0254	33,6577	66,3673
22		17:00-17	70,20	5,3327	1,3863	2,6391	3,4340	5,1533	1,3863	1,9459	3,0910	5,9402	2,0794	3,0445	3,9703	44,9009	54,5306
23		17:15-17	70,20	5,3936	1,6094	2,1972	3,5835	5,1180	1,7918	1,9459	3,1355	5,9584	2,3979	2,7726	4,0775	46,3423	53,7687

Figure 7: Illustration of the data entered into SPSS

The Equation 1 shows the best model obtained by statistical analysis performed by that software.

$$\mathrm{Leq} = 23{,}234 + 1{,}307.\mathrm{Ln}(\mathrm{A}_{\mathrm{ad}}) + 0{,}432.Ln(O_{ad}) + 1{,}368.Ln(Vm_{ad}) + 1{,}057.Ln(A_{op}) + 0{,}863.Ln(O_{op}) + 1{,}543.Ln(Vm_{op}) + 0{,}432.Ln(M_{ad} + M_{op}) + 0{,}951.Ln(\%P) + 13{,}915.(H) - 0{,}391.(D) \quad (1)$$

Where:

• Leq is the equivalent sound level (15 minutes);

• Ln (Aad) is natural logarithm of the flow of cars towards adjacent sidewak to the receiver (15 minutes);

• Ln (Oad) is natural logarithm of the flow towards the bus adjacent sidewak to the receiver (15 minutes);

• Ln (Vmad) is natural logarithm of the average velocity of flow in the adjacent sidewak to the receiver (15 minutes);

• Ln (AOP) is natural logarithm of the flow of cars in the opposite sidewak direction to the receiver (15 minutes);

• Ln (Oop) is natural logarithm of the flow of buses in the opposite sidewak direction to the receiver (15 minutes);

• Ln (Vmop) is natural logarithm of the average velocity of flow in the opposite direction to the receiver (15 minutes);

• Ln (Mad + Mop) is the natural logarithm of motorcycle flow in both directions (15 minutes);

• Ln (P%) is natural logarithm of the percentage of heavy vehicles (15 minutes);

• H is road hierarchy;

• D is the distance in meters between the source and receiver (center of the track).

On the Table 1 can be verified that the coefficient of determination statistic R^2 obtained for the calibrated model is significant (greater than 0.8) and even showed a high value for F test (greater than 100).

Table 1: Results summary for Model

Modelo	R	R2	R2 ajustado	Erro Padrão de Estimativa	Teste F	df1	df2	Sig.
1	0,908	0,825	0,819	1,36188	137,899	10	292	0

4. Simulations of Changes in Modal Split of Passenger Transport

In the following items (including this) will be made to the model simulations to identify the changes in noise levels. Due to the significant number of intervals tested, the results will be compared primarily on the basis of the average equivalent sound level (Leq) for all intervals, which does not invalidate the analysis. A specific evaluation point should be performed in cases of actual practical applications of the model, which is not necessarily the main goal of this work. As previously stated, the transportation system operates, in general, with spare capacity of around 45%. However, when looking at the peak and the effect of higher demand, it appears that this number drops to around 25% (considering all modes). When this analysis is done only for the collective mode (bus), the idle drops to around 20% in the afternoon peak towards higher demand (center>> neighborhood).

Thus, the purpose of this item is to simulate what would happen if the noise part of idleness would be used properly with the optimization of the system without necessarily cause loss of comfort for users, ie, with the average maintenance occupations obtained for all vehicles.

We applied the model to the current settings of occupancy vehicle modes and the number of people who were traveling in that interval. We obtained the modal split also present. From this point, it was simulated to move users from cars to buses, so that in each interval of 15 minutes, it was added 5% more than the percentage of trips made by bus mode, with compensation on trips by mode car.

The results in terms of lower average number of vehicles in circulation is around 4%. Mister does point out that, due to no change in the average occupancy of buses, it was necessary to add more vehicles to the system. Thus, the equivalent average sound level for all intervals increased from 72, 84 dB (A) to 72.74 dB (A), which in terms of quadratic pressure represents a decrease of about 2% (calculations made on a scale logarithmic).

This small reduction is due basically to two factors. The first is already set to increase the number of buses in circulation, the second is that, due to decreased traffic flow was an increase in average speed. As seen in previous chapters, for data collected in this study, the variation of average speed (km / h) with vehicular flow per lane occurs every fifteen minutes at a rate of -0.072 (tangent of the equation $y = ax + b$). That is, for every 100 vehicles unless the flow (per lane), there is an increase of about 7.2% in speed.

Moreover, it is worth pointing out that the calculation was done for the average values over all days. At peak times or situations of forced flow, the behavior tends to be different.

Doing the same analysis of this item (5% increase in the use of buses) and also increasing the average occupancy of buses by 10%, it appears that in this scenario, there is no need to increase the fleet in circulation. Rather, there is a decrease. Thus, the variance of the noise averaged 6%, from 72, 82 dB (A) to 72.58 dB (A), considering the increase of noise due to the increased speed.

The value found is also low. The fact that explains this result is that, despite the reduction in vehicular traffic have been higher, the speed increase also was offset, in part, the decreased number of sources (vehicles).

In a final scenario simulations performed as previously considered a 15% increase in average occupancy of buses, an increase of 5% for use in this way, and occupancy of cars and bike equals 2 passengers per vehicle. These changes imply a reduction of about 16% of the number of vehicles. With this, the theoretical decrease in terms of sound pressure, considering the change in the average speed is about 13% to an average Leq 72.26 dB (A).

Overall, it appears that reductions in noise levels, even with significant changes in the behavior of trips made, are not expressive. The fact is primarily due to compensating for the decrease in average velocity of flow in circulation.

4.1 Increased Average Occupancy Vehicle (Car)

The overall average occupancy of passenger cars is 1.44 per vehicle. Was simulated what would happen to the levels of noise, if this figure rose to two passengers per vehicle, considering that users no longer use their own cars through some action successful management of mobile-type car pooling or car sharing, etc.

Preliminarily, it appears that, with only this change would mean a reduction of 20% of the number of vehicles, considering both directions of traffic on the corridor and the change in modal split throughout the day.

When is the calculation of Leq average for all intervals of measurement made, it appears that there is a reduction of 0.58 dB (A), from 72.82 dB (A) to 72.24 dB (A). Despite the reduction in the decibel scale is small in terms of sound pressure, the reduction is about 13%.

The Figure 8 shows the variations obtained with the change in average vehicle occupancy, where it notes that further reductions will be felt in the early morning, whereas the four reduction peaks clearly visible in Figure 5 are around: 30h in the morning. The fact that this happens as time begins to urban activity with increasing flow. Once the background noise is low, any change is readily apparent. Thus, the decrease in the number of vehicles would cause more noticeable effects on noise levels. In these times, the percentage reduction of the quadratic pressure would be about 23%.

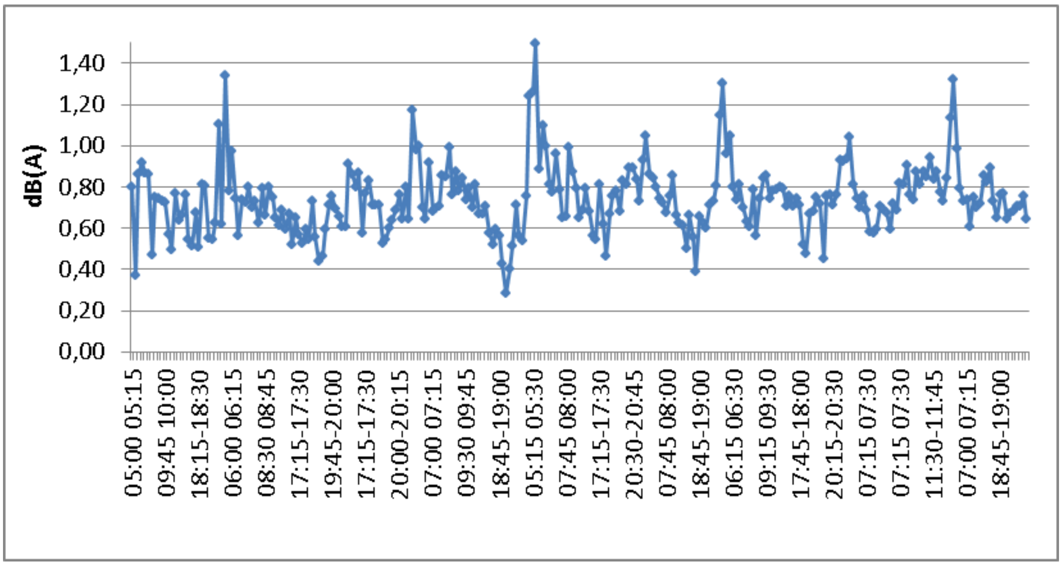


Figure 8: Variation in noise recorded according to the hours of the day

However, the evaluations did not consider the increase of the average velocity of flow due to a reduction in the number of vehicles. When considering this correction to the average Leq is obtained 72.45 dB (A) so that the reduction of noise level caused by the increase in average vehicle occupancy in terms of pressure, would be about 9%. That is, even with a reduction of approximately 20% of vehicular flow, compensation occurred due to increased speed virtually cancels the reduction achieved by the reduction in movement of sound sources (vehicles).

4.2 Increase in Average Occupancy Vehicle (Bus)

Also as seen in Chapter 4, the average occupancy peaks occur in the afternoon and with values of around 55 passengers per vehicle. Whereas, in general, the average capacity of the buses in the city of Belo Horizonte is 80 passengers, was simulated an increase in average occupancy of 10% bus.

By doing this, there is an average reduction in the number of vehicles of almost 1%. Considering the low reduction in the number of vehicles, coupled with the compensation due to increased average speed, noise reduction is negligible, from 72.84 dB (A) to 72.74 dB (A), which represents a reduction of sound pressure level of about 2%. Anyway, the analysis of Figure 3 August shows that the major trends of reduction peaks occur in the morning, where the flow of buses is higher.

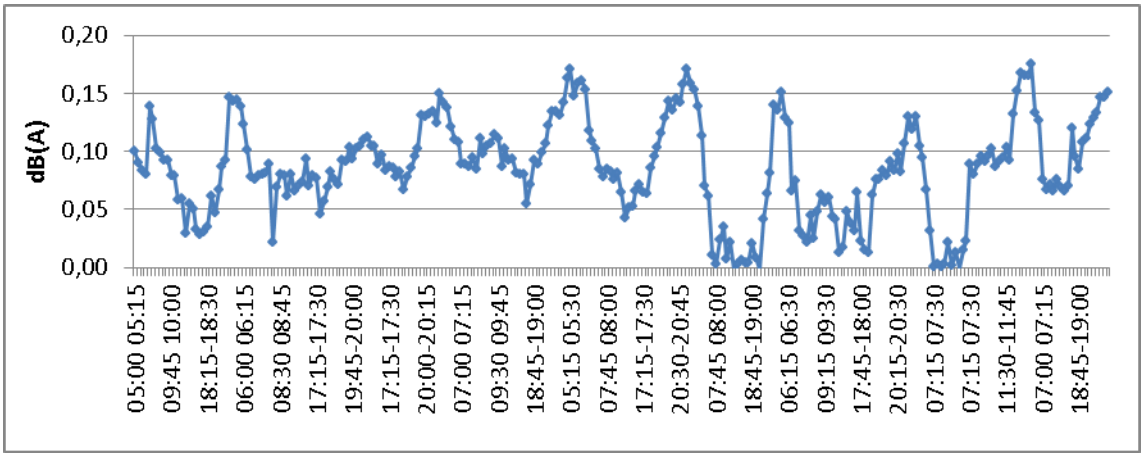


Figure 9: Variation in noise recorded depending on time of day for this scenario

4.3 Increased Occupancy Average Motorcycles

Also simulated the reduction of motorcycles in circulation due to an increase in its occupancy, in a hypothetical situation where it would have an occupancy of 2 passengers per vehicle. With this occupation and maintaining the modal split, the decrease in traffic flow would be about 2.9%.

In this scenario there would be no change in average velocity of flow, since motorcycles have little or no influence on this parameter. Thus, also due to the small change in traffic flow, noise reduction (average Leq) would be minimal, from 72.84 dB (A) to 72.76 dB (A), which in terms of pressure represents a reduction of 1.8%. Similar to the previous simulations, the downward trend, even if very small, occurs most strongly in the morning, due to factors explained above.

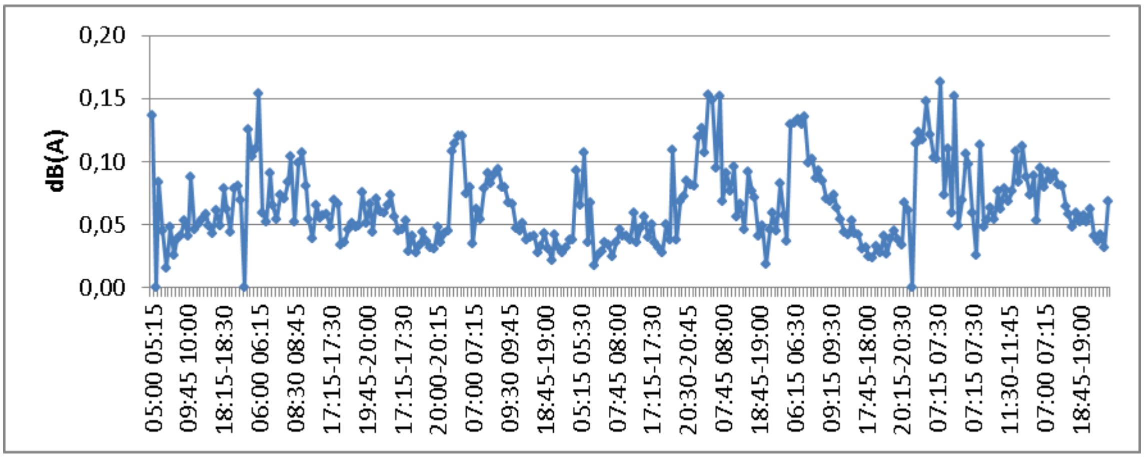


Figure 10: Variation in noise recorded depending on time of day for this scenario

4.4 Amendment of Joint Occupancy Vehicle Average

In this scenario, the average occupancy of cars, buses and motorcycles have undergone the same changes made in the previous items, however, will evaluate the effects of these changes together.

The average reduction in the flow of vehicles is around 27%. Considering the ever increasing speed, reducing noise (Leq average) rate was 16%, from 72.84 dB (A) to 72.08 dB (A).

It is an average value, in general, already considerable. However, this figure is simulated average for all intervals of Leq obtained throughout the day, a situation that finds little to influence the degree of saturation which, as shown, has a direct influence on noise levels.

5. Conclusions

Overall, it appears that, in most simulated scenarios, the decrease in average noise observed was small or even no expression. Attributed this behavior to be broadly offsetting decrease flow and increase in average speed due to improved operation of urban traffic.

Another point to be made is with regard to the calibrated model. As observed in the data used, it is inferred that in a few moments we obtained forced flow in the magnitude observed in the qualitative analysis that assessed the relationship with the degree of saturation. Thus, it may be only slightly sensitive to these variations to saturation values very close to or even greater than 1 (demand greater than capacity). Thus, an analysis that showed virtually no reduction could produce negative, ie, by reducing the flow and increase in speed, noise would increase.

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