Defining vehicular noise levels to manage risk associated with exterior facade design

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ABSTRACT

Evaluation and mitigation of noise from vehicular sources is common as a building design criterion. In the United States of America (USA), it has been part of U.S. Department of Housing and Urban Development (HUD) multifamily building design requirements since the 1970s. It is included in numerous state and local planning requirements, and also has recently been added to various Green Building Design Standards, including school and healthcare facility design guidelines. In California, the building codes include mitigation of traffic noise sources for all multifamily and most commercial projects. These criteria specify an allowable noise level, but do not provide a method for defining this level given the statistical variations. For sources with large variations, the method of defining the level can greatly affect the building façade design and the occupant experience. Further, it may be necessary to determine this level from relatively brief measurements. This paper examines the factors that should be considered when defining the exterior noise from vehicular sources. Methods for predicting the noise level using data are evaluated, and minimum survey requirements to determine specific exterior noise parameters are suggested.

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1. INTRODUCTION

Traffic noise is a common acoustical source impacting all building types and has been the subject of considerable study. One of the major sources of uncertainty in a traffic noise measurement is the inherent variation in the traffic noise levels due to changes in traffic volume, speed, weather, etc. During a long term measurements, many such variations will average out. Criteria used to evaluate traffic noise have typically used long-term average metrics, which reduce the uncertainties due to variation in traffic noise.

However, recent Green building criteria have required the evaluation of the loudest hour instead of an average over some time period (typically 24 hours). For any measurement, the variations in maximum level will be considerably higher than the variations in the average level. The inherent variation in source noise level is more important than with traditional average metrics because the smoothing effect of the averaging procedure does not occur. Larger uncertainties means a greater risk that a measurement or calculation procedure obtains a result significantly higher or lower than the "true" value, and the subsequent over or under designing of the project's exterior façade noise isolation. This leads to a reduction or increase in the interior noise level potentially affecting the occupants

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2. BUILDING CODES AND REGULATIONS

2.1 Daily Metrics

In the USA, noise from transportation sources has long been a part of codes and guidelines for residential projects, and the noise level has been evaluated in terms of daily metrics such as L_{dn} and L_{den}. The U.S. Department of Housing and Urban Development (3) defines an acceptable acoustical environment in terms of L_{dn}. In California, the state building code (4), as well as the General Plans of many municipalities, similarly defines noise level requirements in terms of L_{dn} or L_{den}.

In Europe, the Environmental Noise Directive (5) defines noise exposure in terms of L_{den} or L_{night} averaged over one year. The American directives do not explicitly state the measurement interval but are also typically reported as annual averages.

2.2 Maximum-Hour Metrics

Recently there have been an increased number of design requirements and guidelines for non-residential projects, many associated with green building guidelines. The California Green Building Standards require that the interior noise level "does not exceed an hourly equivalent noise level (Leq-1Hr) of 50 dBA in occupied areas during any hour of operation" (6). This applies to most non-residential projects.

Green building guidelines for schools, such as the Collaborative for High Performance Schools, reference ANSI S12.60. The requirements for noise from exterior sources are defined in terms of "the noisiest continuous one-hour period during times when learning activities take place" (7). LEED v4 BD+C: Schools "requires mitigation for high-noise sites (peak-hour Leq above 60 dBA during school hours)."

None of these documents provide any definition, procedures or guidance regarding how the "loudest hour" should be defined. It is trivial to compute the loudest hourly Leq of any given measurement time period, but how does one account for day-to-day variations in noise level? Presumably one should select the maximum hourly level that is "typical" for the measurement location. Even if given a large data set encompassing the full range of variation, which level does the acoustician define to be "typical"?

Currently, acousticians faced with these questions have simply measured over a single day and used the loudest hour to perform calculations. There has been insufficient consideration of the variation of the sound level, and whether the measurement constitutes adequate sampling to have confidence that the reported sound level is accurate.

2.3 Defining Maximum Hour

The "maximum" level of a data set, assuming an approximately normal distribution, should not be defined as the loudest level measured but as the level that is two standard deviations above the mean. This is an arbitrary but common convention in many branches of science and engineering, corresponding to approximate 95 percent confidence interval about the mean. It is the 97.5 percentile of the distribution.

One reason for this definition is to avoid the effects of anomalously loud intervals. The very loudest elements of the data set are atypical by definition, and it is reasonable to exclude the top few percent of the tail of the distribution when determining the maximum value that can typically be expected.

Another reason is related to the effect of the length of the measurement period on the measurement result. For measurement periods of adequate length, an anomalously loud single measurement will have only a small effect on the average. However, assuming that maximum level events occur in an approximately normal distribution, the longer the measurement period, the more likely it will capture events from the high-side tail of the distribution. In other words, longer measurement periods will result (on average) in higher maximum event levels!

Regulations have been mostly average metrics in the past, so the acoustical community is familiar with the concept that a longer measurement period will give a more accurate result. If the maximum is defined simplistically as the loudest measured interval during a measurement, increasing the length of the measurement will not provide a more accurate result. However, if the maximum level is defined based on the mean and variance of the distribution, then a longer measurement period will better define these parameters and hence give a more accurate result.

2.4 Computer Models

Calculation of noise levels is preferred over measurements for many jurisdictions. A model may be able to provide an annual average better than a short-term measurement. The same should be true for maximum criteria. However, the authors are unaware of a calculation method that outputs the maximum hourly level in addition to an average. Unlike average metrics, maximum criteria have not been extensively measured and modeled at this point.

3. MEASUREMENT PROGRAM

The next step is to quantify the distribution of hourly L_{eq}'s to determine the maximum hourly L_{eq} using the above definition. There have been previous measurement surveys documenting the variation in noise level (8, 9, 10), but all have focused on average metrics. Evaluating the maximum level requires a different level of type of analysis. Long-term noise survey of roadways was begun, with an aim to determine not just the average level but the distribution of hourly levels.

3.1 Long term traffic noise survey

Measurements were performed on several arterial roadways and freeways. The results from one arterial and one freeway are presented here. Both the roadway and freeway presented are within California. The weather over the period of measurement is mostly dry with favorable driving conditions, with several days of rain.

The arterial in questions is a 4-lane road with a wide median and a 40 mile per hour (65 kilometers per hour) speed limit. A microphone was mounted to the rooftop of a building at the façade facing the street. This location had unobstructed exposure to all four lanes in both directions at an approximate elevation of 6 meters. A Bruel & Kjaer type 2260 sound level meter logged the noise level at high time resolution from February 11 through March 14, 2014.

The freeway has eight lanes (four in each direction). There is a wide median with a shoulder (breakdown lane) in each direction separated by a low concrete wall that does not block line of sight to any of the lanes. The speed limit is 65 miles per hour (105 kilometers per hour), but free flowing traffic often moves at approximately 120 kilometers per hour. The average daily traffic volume is approximately 145,000. The freeway is lower in elevation than the surrounding streets. The microphone was mounted on the roof of a building overlooking the freeway with unobstructed exposure in both directions. The measurement location was about 30 meters from the centerline of the freeway, and approximately 10 meters above the road surface. A Bruel & Kjaer type 2260 sound level meter logged the noise level at high time resolution from January 17 through March 14, 2014.

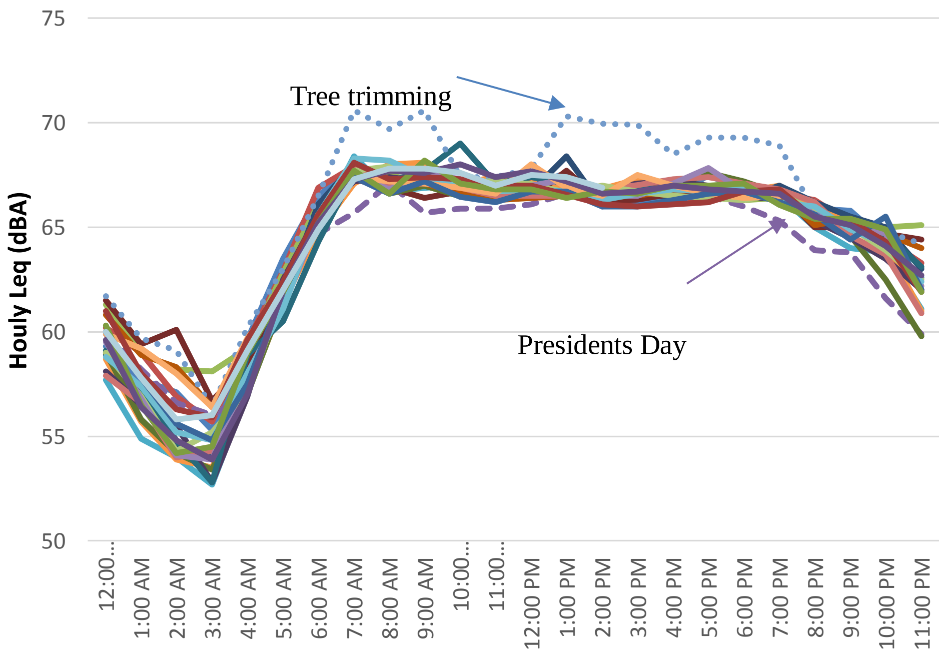

Figure 1 – Arterial Hourly Leq's for all weekdays measured.

3.2 Results – Arterial

The data was reduced to hourly intervals synced to the clock for this analysis. The weekends were significantly quieter than the weekdays and were excluded from the analysis since the goal is to locate the maximum hour. The hourly Leq's for all weekdays are shown in Figure 1. The dashed lines show February 17, which was the Presidents Day holiday (in the USA), and had slightly reduced noise levels. The dotted line shows a day when work crews were conducting tree trimming on the street (in the median of the arterial).

During the daytime hours (from 7:00 AM to 7:00 PM), there is very little variation in level, both day-to-day and from hour-to-hour within a day for a free flowing arterial. In fact, over the 22 weekdays in the measurement period, the daytime hourly Leq ranged from 66–69 dBA. Because the spread in the data was so small, we analyzed the data at a resolution of a tenth of a dB in order to reduce rounding errors. The average hourly Leq was 67.0 dBA, and the standard deviation was 0.5 dB. The "loudest hour" of two standard deviations above the mean is therefore defined to be 68.0 dBA. (Note that the mean and maximum values have tenth-dB resolution and are not rounded. It is coincidence that they happened to end up on zero tenths.)

3.3 Results – Freeway

For the freeway, the weekends were not significantly quieter than the weekdays but had substantially higher variation, so the weekends were also excluded from the analysis. The hourly Leq's for all weekdays are shown in Figure 2. This stretch of freeway is free-flowing for most of the day, except for the afternoon when there is heavy congestion in the eastbound lanes from roughly 3 pm to 7 pm each weekday. From Figure 2, there is no obvious reduction in level during those hours, even though half of the freeway is stopped.

There are clearly hours where the noise level decreases substantially, which are presumably due to a temporary slowing of traffic on both sides of the freeway due to anomalous events such as road construction or traffic accidents. The dashed line is the level on February 14, which was Valentine's Day holiday; whether this is the cause of the traffic congestion is unknown. Presidents Day (February 17) holiday did not show any particular variation from the average. Aside from these atypical events, the daytime levels are remarkably constant, and stay within about a three dB range from 5 am to 11 pm.

During the daytime hours (7:00 AM to 7:00 PM), the average hourly Leq was 76.7 dBA and the standard deviation was 0.65 dB. The "loudest hour" defined as two standard deviations above the mean is therefore 78.0 dBA.

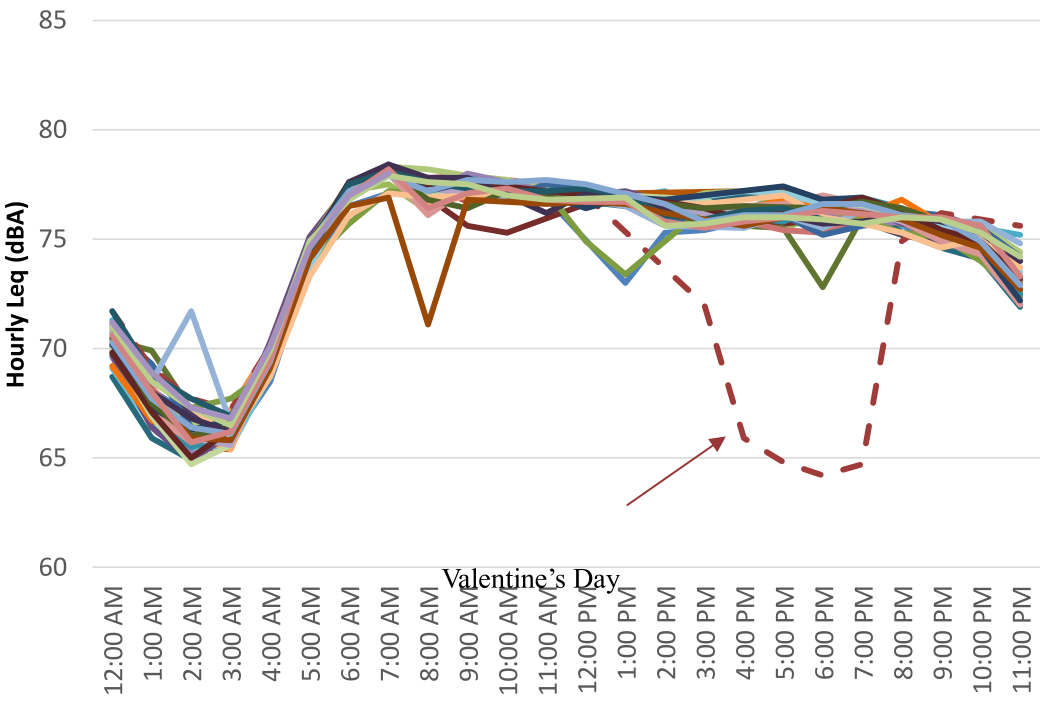

Figure 2 – Freeway Hourly Leq's for all weekdays measured.

3.4 Comparison

Figure 3 shows the average hourly LAeq for all of the measured weekdays for the freeway and arterial. The curves are offset for comparison; the freeway is almost exactly 10 dB louder. Aside from the level difference, the two curves are strikingly similar. We have the following observations:

- The patterns mirror the activity of the roadways that is correlated with human activity.
- For both, the 7:00 – 8:00 AM hour is the loudest hour of the day.
- The arterial daytime levels are surprisingly consistent. The variation is less than 1 dB from 7:00 AM to 7:00 PM
- The freeway daytime levels are slightly less consistent, and there is an average decrease in the afternoons by about 1 dB. This is presumably due to the large reduction in vehicle speed of the eastbound lanes during this period.
- In the early morning, the freeway noise levels start getting louder about one hour earlier than the arterials. Similarly, in the late evening, the freeway levels maintain their average for about one hour later than the arterials before declining.
- For both, the hour-to-hour variation was so small that the difference between the average and the loudest hour was only about 1 dB (1.0 dB for arterials and 1.3 dB for freeway).

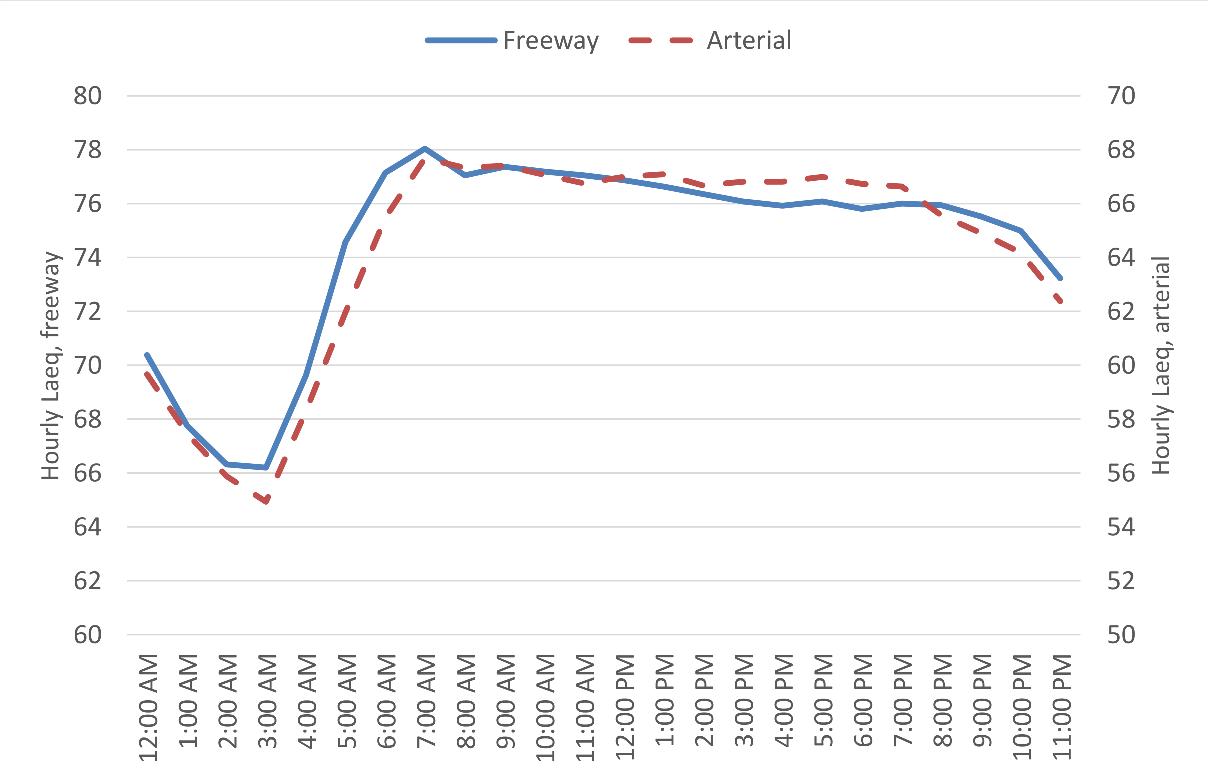

Figure 3 – Comparison of average weekday hourly LAeq for arterial and freeway

4. REQUIRED LENGTH OF MEASUREMENT

The above measurements have determined the “true” average and maximum hourly levels for these two types of roadway. For a typical investigation, the measurement period will be much shorter. How long does the measurement period need to be to ensure an accurate result?

4.1 Monte Carlo Method

The Monte Carlo method is ideal for this analysis. We use a random number generator to randomly select a start hour from the data set. From the start hour, we calculate the average noise level (Leq) that would be achieved after measuring for *n* hours, so that *n* is the length of the measurement. For each *n*, we repeat for a large number of trials and plot the results. The distribution of the results gives the probability of measuring that level after a measurement that is *n* hours long. The process is repeated with different values of *n*.

As an example, results for an analysis with 1000 trials on the freeway are shown in Figure 4. The "true" mean is 77 dBA, and as expected, the probability of measuring the mean value approaches 100 percent as the length of measurement increases. The probability of measuring above or below the "true" mean also decreases so the length of measurement increases, so that the distribution becomes narrower.

Once the average value is determined, the hourly maximum value is determined from the standard deviation, which has been previously determined from measurements on similar roadways. Alternatively, the standard deviation can be estimated from the measurements; this method is not discussed here.

4.2 Length of Measurement Predictions

Given the above information, we can evaluate methods for determining the level of the loudest hour for an actual project on this or a similar roadway having similar conditions. Because this approach yields actual probabilities, it yields the information that a stakeholder may use to balance the risk and the cost.

For comparison, consider an alternative method that does not use the probabilistic analysis. Recall that 95 percent of a normal distribution is contained within plus and minus two standard deviations from the mean. We can take a measurement and simply add *four* standard deviations to the value, so that even if we are unlucky and measure a result two standard deviations below the mean, we will arrive at the correct maximum level. The problem of course is that this is very conservative and overestimates the level for most measurements. For the roadways studied this is not significant, as four standard deviations is only about 2 dB. However for more variable sources (like trains), the conservative estimate could lead to significant overdesign.

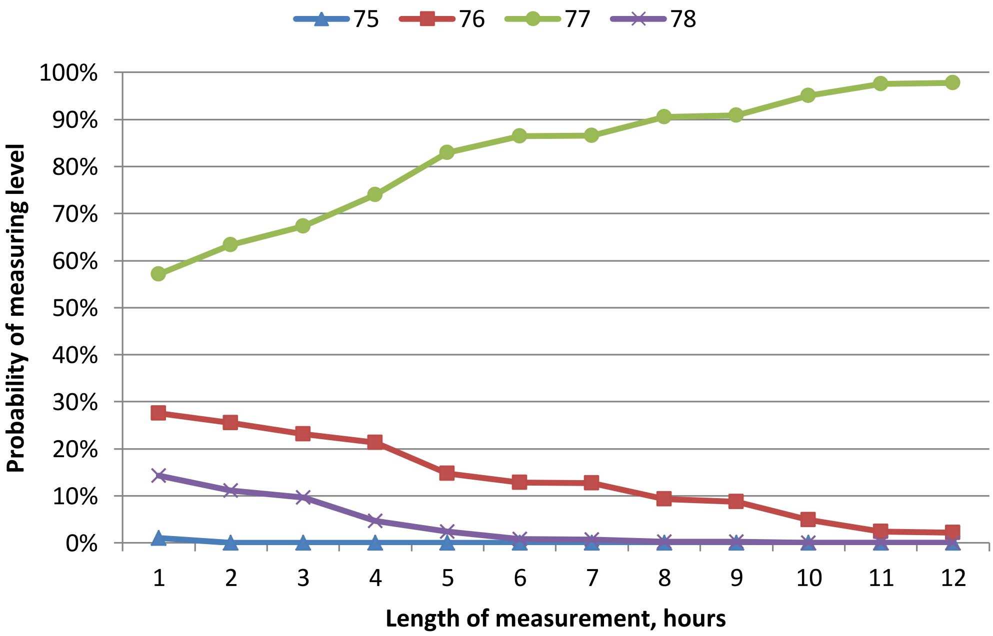

Figure 4 –Monte Carlo analysis for the freeway showing the probability of measuring the indicated average noise levels as a function of measurement length.

A better approach is to use information to balance risk and assign resources. While a slightly conservative estimate is appropriate, it is generally important to avoid underestimating the measured level, which could lead to interior levels that exceed the criteria. Using Figure 4 as an example, there is a 29 percent chance of measuring 76 dBA or less and possibly under-designing the project because the measured noise level is too low leading to lower isolation values. Measuring for 4 hours reduces this percentage, but only to 21 percent. The consultant has several options. One is to take a long term (full day) measurement to determine the average level to a high degree of confidence. Another option is to take a short term measurement and add additional dB to the result. This allows a shorter measurement but at the risk of overdesign. Depending on the sensitivity of the project and how close the project is to the design criteria, the consultant can determine how to allocate resources.

4.3 Other Metrics

The above analysis is not limited to the maximum hour but can be used for any metric that can be correlated with the daytime noise level. For example, some European criteria are written in terms of the average nighttime noise level, L_{night}. From reference 3, the difference between the daytime and nighttime average levels ($L_{day} - L_{night}$) is relatively constant for a given roadway, and this was confirmed in our studies. For the freeway, for example, $L_{day} - L_{night}$ was nearly constant at 4.0 dB with a standard deviation of 0.38 dB. Therefore, the above approach to balancing risk with length of measurement could be just as easily applied to estimating L_{night} (or L_{den}) instead of the maximum hourly level.

5. SUMMARY

Several Green building guidelines have recently been introduced that describe exterior noise in terms of maximum hourly L_{eq} instead of the more typical average such as L_{den} or L_{night}.

Compared to traditional traffic noise measurements, there is increased uncertainty and therefore risk because the maximum hourly level is not well defined. Without a good definition, simply increasing the length of the measurement does not increase the accuracy of the measurement. Following common science and engineering practice, we define the “loudest hour” as two standard deviations above the mean (97.5 percentile).

The loudest hour is therefore determined by long term measurements to quantify the temporal distribution of the source levels. For both arterial roadways and freeways similar to the roads in this study, the loudest levels are in the daytime hours from 7:00 AM to 7:00 PM. There is remarkably little variation in noise level, both hour-to-hour and day-to-day. The mean and variance are calculated from the measured data and the loudest hour is determined as two standard deviations above the mean.

For real-world projects, very long term measurements are not practical. It is possible to accurately estimate the “true” long-term maximum hourly level from short term measurements. The accuracy of the estimate depends on the length of the measurement and the safety factor added to the measured value. The consultant can adjust these parameters based on the specifics of the project to optimize resources while minimizing risk.

The same method is not only useful for estimating the maximum hourly level, but can be applied to any other metric that can be related to the daytime level, such as L_{night}.

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