

Uncertainty Analysis of the Harmonoise Road Source Emission Levels

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Following the publication of the Harmonoise methodologies, research has been carried out investigating the effect of uncertainty in the road traffic source parameters in order to assess the relative significance of each input dataset. Using Monte Carlo Simulations, a series of possible inputs were generated for each source parameter, and the respective emission level calculated, creating a distribution from which the uncertainty in the input could be expressed directly as uncertainty in the decibel emission level. Assessments of the source parameters were conducted both individually and simultaneously. This paper presents the results of this research, and draws parallels between data accuracy and the accuracy of predicted emission levels. It is envisaged this research can aid the design of datasets to increase the quality and reliability of source emission levels.

1 Introduction

Following the European Commission requirement for Member States to compile noise maps of agglomerations, questions have been raised regarding the quality and reliability of noise maps and whether techniques can be applied to expose the uncertainty contained within calculations. The recently published Harmonoise[1] methodologies, which are to be used in the second round of noise mapping in 2012, have been developed with strict tolerances on the prediction accuracy. It is claimed by the Harmonoise Project that the accuracy of a calculation using Harmonoise will be predominantly due to the accuracy of the data fed into the model.

Using Monte Carlo Simulation (MCS) as a method of conducting uncertainty analysis and error propagation tests, initial investigations into the effects of parameter uncertainty on the Harmonoise road source emission model have been assessed.

2 The Harmonoise Model

2.1 Prediction Method

The Harmonoise road source emission model has been developed to calculate sound power source levels at three separate source heights. For the three vehicle categories used, the effects of gradient and road surface type are common, whilst the vehicle flow, velocity, and acceleration can be set individually.

A source at 0.01m describes the noise created by the interaction of the vehicle road surface contact and is contributed to by all three vehicle categories. Two other sources at 0.3m and 0.75 meters model the traction noise from the vehicles. The source at 0.3m is contributed by category 1 vehicles only, whilst the source at 0.75m has contributions from both category 2 and 3 vehicles. This paper will refer to the 0.01m source as source 1, 0.3m as source 2 and 0.75m as source 3.

Harmonoise assesses the source sound power levels in third octave bands, with coefficients for rolling and traction noise determining the emission level in each frequency band. The traction and rolling noise are functions of vehicle velocity. Vehicle flow is used as an attenuation factor based upon a reference flow. Vehicle acceleration is considered with road gradient. Road surface correction is included as a function of vehicle velocity based upon coefficients derived from CPX measurements. The authors have not been able to obtain any coefficients for road surface types and therefore the road surface correction has not been assessed in this study; instead example corrections obtained from the Harmonoise appendix have been used.

3 Monte Carlo Simulation (MCS)

3.1 Introduction

Monte Carlo Methods are an individual branch of mathematics which are based around the use of random numbers to solve complex problems. The use of Monte

Carlo Simulation in uncertainty analysis has been successfully applied in several professions such as Air Quality and Water Resource Engineering to assess the impact of parameter uncertainty on a calculated value. Research showed MCS to be a preferred method of uncertainty analysis for the evaluation of error propagation in the Harmonoise source emission terms in comparison to more analytical methods.

3.2 Theory

MCS is a stochastic process which relies upon a calculation method being treated as function for a series of possible input values. A parameter is assigned a probability distribution function (PDF) which best reflects its measurement. The uncertainties of the parameters are defined in terms of a relative percentage or absolute error. By randomly sampling from the PDF of the input parameters this obtains values for which a calculation method can be run and the output realized.

This process is repeated for 'n' iterations hence deriving the PDF of the output which can then be manipulated using statistical measures such as a standard deviation to assess uncertainty. Many researchers recognize MCS as an accurate method of determining uncertainty but stress its accuracy is limited by the number of iterations used.

4 Method and Preliminary Tests

A program was developed in MATLAB which would allow Monte Carlo Simulations to be performed on the Harmonoise source emission model. All parameters were assumed a normal distribution of error with uncertainty in the input being defined as a relative percentage of the input value and 3 standard deviations from the mean (99.8% confidence). Figure 1 shows an example of this assumption.

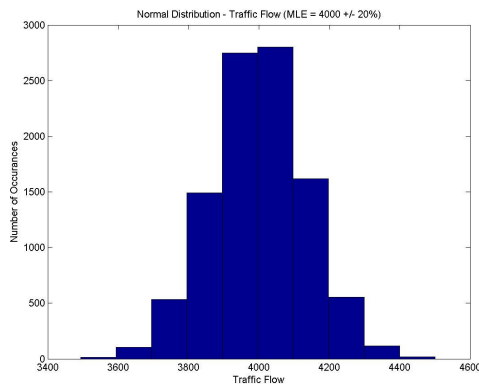


Figure 1: Example input distribution

A convergence test was performed using this setup, and the stability of the statistical properties of the source level PDF's monitored against the number iterations used during the calculation. It was found that using 2500 iterations would allow good stability and reliability to the second decimal place of the results. Increasing the number of iterations was found to provide increased stability in statistical measures but significantly increase the computational load and calculation time required at no significant benefit.

The general behaviour of the propagation of uncertainties through the Harmonoise method was assessed in a series of preliminary tests. As no previous published research was found the preliminary tests governed the options for the testing methodology.

The first set of preliminary tests assessed the overall A-weighted levels of all three sources directly against relative uncertainty in each of the input parameters. The results of this showed from an early stage that, apart from some minor trends, there was no direct connection apparent between the uncertainty in the overall source emission levels and the uncertainty in any of the individual input parameters. Although it was observed that, in general, increasing the uncertainty in the parameters did yield a higher level of uncertainty in the source emission levels, no significant trends were identified in its pattern of increase, leading to no specific conclusions.

Further investigations were then made assessing the uncertainty in the each of the third octave band levels for each vehicle category and associated source.

A general scenario was designed with $\pm 10\%$ relative uncertainty specified in the each categories vehicle flow and velocity. All other factors were set as certain. Table 1 shows the scenario adopted.

	Source Parameter	
Category 1 Vehicles	Hourly Traffic Flow (q_1)	3188
	Mean Traffic Speed (v_1)	112kmh
	Acceleration (a_1)	0ms ⁻¹
Category 2 Vehicles	Hourly Traffic Flow (q_2)	735
	Mean Traffic Speed (v_2)	112kmh
	Acceleration (a_2)	0ms ⁻¹
Category 3 Vehicles	Hourly Traffic Flow (q_3)	327
	Mean Traffic Speed (v_3)	92kmh
	Acceleration (a_3)	0ms ⁻¹
	Gradient	0 radians

Table 1: General Scenario

5 General Behaviour

The results from the initial scenario showed some interesting trends. In assessing source 1 it was found that some of the category contributions at certain third octave bands had uncertainties of $\pm 1\text{dB}$ with variation in the extent of uncertainties across all third octave bands. On the summation of the individual category contributions, the maximum uncertainty in the overall third octave level of source 1 was $\pm 0.6\text{dB}$, less than that of some of the individual category contributions. Finally, the uncertainty in the overall A-weighted source level was found to be $\pm 0.4\text{dB}$. In addition it was also found that the maximum level in the third octave bands had no connection to the maximum uncertainties. This scenario, as with many others assessed, shows that large uncertainties can be present in the individual third octave band level calculations but they do not necessarily propagate through to the final overall source emission level. This trend was also shown to occur with sources 2 & 3. Figure 2 shows the histogram for the overall A-weighted level of source 1.

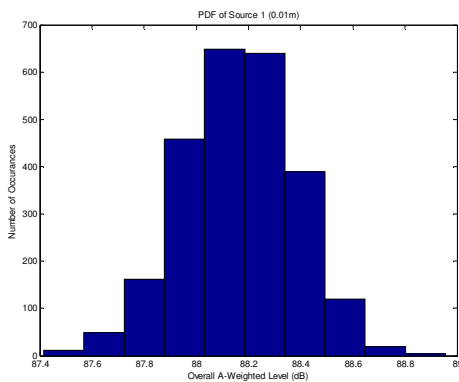


Figure 2: Output distribution

The general behaviour indicated that the propagation of uncertainty through the source emission model is not just a factor of parameter uncertainty, a situation which is unlike the behaviour identified in other road noise source emission models such as CRTN & XPS 31-133.

Further investigations were carried out to identify what other factors effect the propagation of uncertainty through the source emission model. By modifying the original scenario, these factors were identified.

The scenario was modified so that uncertainty in the category 2 & 3 velocity and flows was set at $\pm 50\%$ with parameter values allowing for low level category contributions. Uncertainty in the category 1 vehicle velocity and flows was set to $\pm 50\%$ with parameter values set to yield larger source levels. Table 2 shows the modified scenario.

	Source Parameter	
Category 1 Vehicles	Hourly Traffic Flow (q_1)	3188
	Mean Traffic Speed (v_1)	112kmh
	Acceleration (a_1)	0ms^{-1}
Category 2 Vehicles	Hourly Traffic Flow (q_2)	50
	Mean Traffic Speed (v_2)	50kmh
	Acceleration (a_2)	0ms^{-1}
Category 3 Vehicles	Hourly Traffic Flow (q_3)	25
	Mean Traffic Speed (v_3)	50kmh
	Acceleration (a_3)	0ms^{-1}
	Gradient	0 radians

Table 2: Modified Scenario

The MCS was conducted and the uncertainty in each of the third octave band category contributions assessed. Figure 3 shows the levels and uncertainty in each of the third octave band levels.

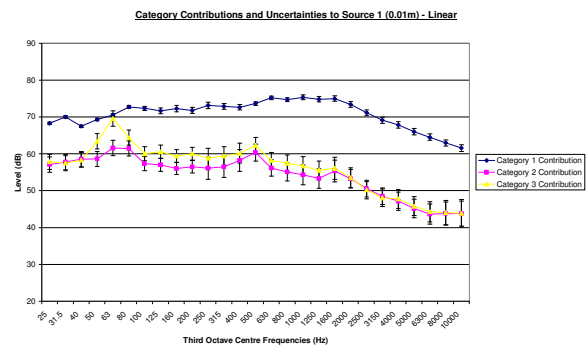


Figure 3: Source 1 Category Contributions

Figure 3 shows that uncertainty of category 2 & 3 contributions is significantly higher than those in the category 1 contributions. The uncertainties in the category 1 contributions were identical to those in the original scenario. This general behaviour, where low emission level sources show a higher degree of uncertainty in the result for the same % of input uncertainty, is similar to the situation found during recent error propagation testing of CRTN and XPS 31-133 [2]&[3].

Figure 4 shows the uncertainty in the overall third octave level for source 1.

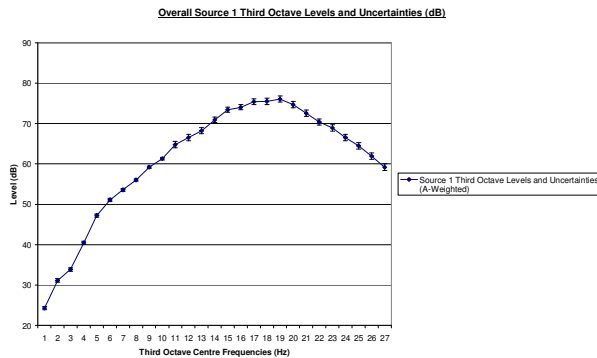


Figure 4: Source 1 Third Octave Band Levels

Figure 4 shows that uncertainty in the overall third octave band levels for source 1 does not reflect the extent of uncertainty shown in the category contributions. By assessing the uncertainty numerically it was found that the uncertainty in the overall third octave band levels resembles those in the highest contribution levels. Table 3 shows an example.

	Third Octave Band Centre Frequency (Hz)			
	250	315	400	500
Category 1 Contribution Uncertainty (dB)	0.86	0.80	0.72	0.49
Category 2 Contribution Uncertainty (dB)	3.00	2.88	2.91	2.29
Category 3 Contribution Uncertainty (dB)	2.63	2.54	2.70	2.23
Uncertainty in Source 1 (dB)	0.80	0.78	0.77	0.68

Table 3: Assessment of Uncertainties

In tests with other similar scenarios using differing parameter values identical behaviour was identified. Since a calculated level is dependant upon all factors in the model, this essentially means that all of the factors will affect the uncertainty in the overall source levels. This makes any assessment difficult as this adds another dimension to the propagation of uncertainty through the model.

In test situations such as this where one vehicle category dominates the total noise emission level, the same vehicle category will also dominate the resultant uncertainty. Whilst this may provide a path for further investigation, it is considered that real world traffic

composition will not be so dominated by one category, hence the degree of complexity in determining the overall uncertainty in the resultant level is increased.

6 Parameter Behaviour

The general behaviour of the propagation of uncertainties through the Harmonoise source emission method makes an assessment for the individual parameters difficult, however there are issues which have been identified. Different levels of uncertainty have been shown in different frequency bands; therefore parameters which control this behaviour were identified. Also identifying frequency dependent effects of the input parameters is advantageous, as well as which sources and categories are more sensitive.

6.1 Traffic Flow

Investigations showed that the nature of the traffic flow correction in the method showed identical behaviour for all three vehicle category contributions, and all sources. Differing category flows and vehicle velocities were found not to affect the uncertainty in the contributions but the actual relative uncertainty to be the critical factor. For example, for a category flow of $2000 \pm 20\%$ and associated velocity of 100kmh^{-1} , would yield identical uncertainty in the source contribution as $300 \pm 20\%$ vehicles and associated velocity of 50kmh^{-1} . This shows that the sensitivity to relative uncertainties is a constant across all flows however sensitivity to absolute uncertainty reduces with flow. A linear relationship was also identified between increasing relative parameter uncertainty and uncertainty in the third octave levels.

6.2 Vehicle Velocity

The assessment of uncertainty in each categories vehicle velocity identified several interesting features. The uncertainties in each category contribution to all sources were found to differ in every case and also in each third octave band.

Figure 5 shows the uncertainty in each third octave band level for category 1 contribution to source 1 at various category 1 velocities, all with a relative uncertainty of $\pm 20\%$.

It can be seen in the figure that for this case there are regions in which the uncertainty in the category 1 contribution for several vehicle velocities are similar. In contrast, there are third octave bands in which the same relative uncertainty yields greater uncertainty in the contribution at different vehicle velocities. This behaviour was not limited to just this example, all results showed indications of variation in the

magnitude of uncertainties across a series of vehicle velocities and third octave bands. An extreme example was observed in the category 2 and 3 contributions to source 3 as shown in figure 6.

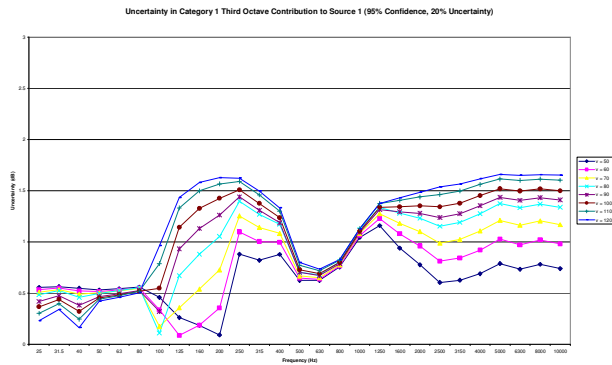


Figure 5: Uncertainty in Category 1, Source 1

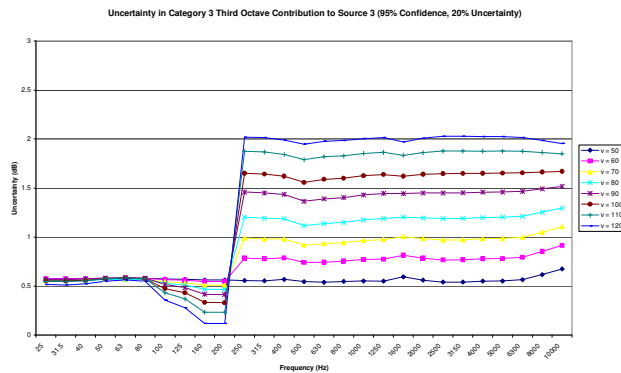


Figure 6: Uncertainty in Category 2&3, Source 1

In figure 6, at low frequencies there is no significant difference, however, due to the magnitude of the traction and rolling noise coefficients, at higher frequencies, the vehicle velocity becomes a factor in the uncertainty experienced by the source contribution. It is the view of the authors that the value of the vehicle velocity should always be considered as a factor affecting the uncertainty in the source contribution as well as the uncertainty itself.

The relationship between increasing relative uncertainty and the uncertainty of the category contribution was found to be linear for all category contributions and for all sources and critically for all third octave bands. Figure 7 shows an example.

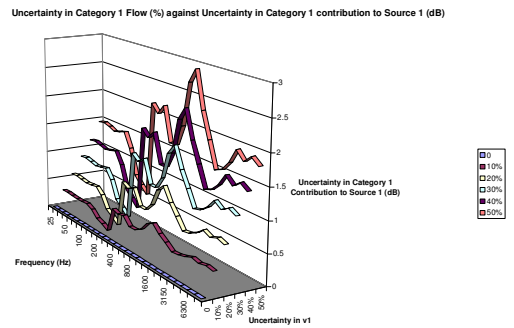


Figure 6: Linear Uncertainty Behaviour

The results presented in this section neglect the road surface correction, which if made using CPX measurement data will not be valid as vehicle velocity is a factor in the correction.

6.3 Acceleration & Road Gradient

Acceleration and gradient corrections are contained within the traction and rolling noise elements which are energetically summed together to form the category contributions to the source.

Although the acceleration correction is linear and has no frequency dependency, due to the nature of the method, the results showed differing levels of uncertainty in each of the third octave band levels. This is due to the rolling and traction noise coefficients and the addition of each noise type. This therefore makes category velocity become a function of the uncertainty. Figure 8 shows a typical response for category 1 contributions to source 1.

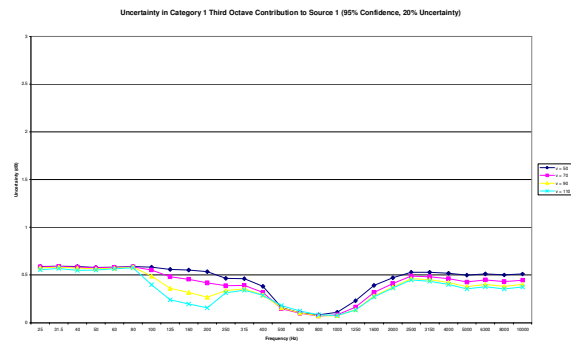


Figure 8: Example Behaviour

Linear behaviour between increasing the relative uncertainty and uncertainty in the category contributions was also observed. In addition, similar uncertainties in the acceleration parameters are more sensitive for sources 2 and 3.

The road gradient showed frequency dependant behaviour in the propagation of uncertainty. However, the uncertainty was identified to be lower in the mid-frequencies. A typical example is shown in figure 9.

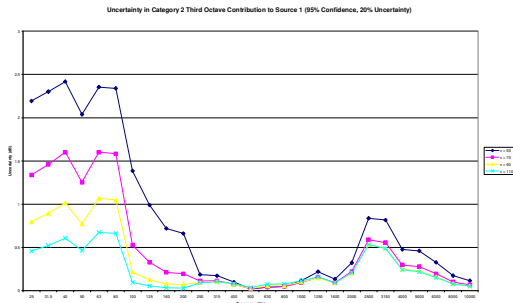


Figure 9: Example Uncertainty due to Gradient Uncertainty

7 Conclusions

The authors have successfully applied Monte Carlo Simulation to the Harmonoise road noise source emission model for the assessment of parameter uncertainty. Research has highlighted the impact of parameter uncertainty on the uncertainty in each vehicle categories contribution to the modelled sources in third octave bands. Therefore probabilistic techniques can be applied to the Harmonoise road noise source emission model to determine the uncertainty in the calculated source emission levels based upon the uncertainty in the parameters.

The propagation of uncertainty to the overall level of the sources, in both third octave bands and A-weighted levels, is dependant upon the magnitude of the relative categories contributions to the source and their respective uncertainties. As a result of this, the design of datasets to an acoustical accuracy cannot be achieved by directly assessing the overall levels of each source but must be made by assessing each categories contribution to avoid creating a multi-dimensional problem. In principle by reducing the uncertainty in the category contributions, the uncertainty in the overall sources will be reduced.

Uncertainties in differing parameters yield different characteristics in the uncertainties in the third octave band source emission levels. Some parameters show greater uncertainties in different third octave levels than others. The application of the A-weighting curve biases the uncertainties in the mid-frequencies towards overall A-weighted level. This means that parameters which yield greater uncertainty in the mid-frequencies will contribute more uncertainty to the overall level.

Results have shown that sources 2 and 3, and their respective category contributions, are significantly

more sensitive to uncertainty than source 1. However, the combined uncertainty due to the source at a receiver location would again be dependant upon the relative levels and uncertainties of the sources.

More focus on obtaining data accurately should be put on the velocity, acceleration and gradient parameters. A logical connection between uncertainty in traffic flows and category levels has been identified therefore making judgements about data quality realistic. Due to the convoluted nature of the other parameters' reactions to uncertainty they must be treated with more caution.

In all cases and all scenarios used by the authors in compiling this research, it was identified that uncertainty in the overall A-weighted levels of the source emission level was less than the uncertainty in the individual third octave band levels. This therefore will lead to strange cases in which detailed assessments may appear to be more uncertain than the single indicator measured used in noise maps.

This initial research has not been able to provide any guidelines or rules which can be used to ensure acoustical accuracy on the input data used with the Harmonoise source emission method. This development means that the Harmonoise source emission method, although designed to be accurate in prediction, suffers as uncertainty in its parameters cannot be directly linked to uncertainty in its resultant emission levels. This development points towards incorporating methods of uncertainty analysis directly within Harmonoise calculations.

Further research is required to extend this work to look at a number of other traffic scenario cases, across a wider range on uncertainties for each of the input parameters. In addition, the probability distributions of the input parameters should also be investigated to ensure correctness within the MCS. The results should also be repeated taking into account road surface types.

References

- [1] The Harmonoise Project, Technical Report HAR7TR041213AEAT04 - Final Technical Report, available at www.harmonoise.org, 2005.
- [2] S. J. Shilton, J. J. A. Van Leeuwen, R. Nota, J. Hinton, Accuracy Implications of using the WG-AEN Good Practice Guide Toolkits, symposium on Managing Uncertainty in Noise Measurement and Prediction, Le Mans, 2005.
- [3] S. J. Shilton, J. J. A. Van Leeuwen, R. Nota, Error Propagation Analysis of XPS 31-133 and CRTN to Help Develop a Noise Mapping Data Standard, symposium on Managing Uncertainty in Noise Measurement and Prediction, Le Mans, 2005.