Spatial Mapping of Noise Measurements and Annoyance Questionnaires to improve the prediction of Traffic Noise Annoyance

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Summary

Currently, traffic noise annoyance estimates are almost exclusively based on exposure-effect relationships derived from linking questionnaires to calculated L_{DEN} noise maps. In particular in situations where local roads, main roads, highways, and railways contribute to annoyance, replacing L_{DEN} with an alternative indicator including these combined diurnal patterns could be advantageous to predict the reported annoyance. The quality of the noise maps is directly related to the quality and the spatial resolution of the underlying traffic data. The uncertainties on the traffic data are rather high for low exposure roads while most of the population is living near these local roads. At the same time, peak levels and diurnal patterns may vary a lot amongst these exposure situations. Hence, performing noise measurement at each dwelling for quantifying exposure and linking it to annoyance surveys could be an alternative, but that is even with cheap distributed monitoring networks difficult to achieve. Spatially mapping of measurement features and surveys might close this gap. The relevant noise features can include noise levels, noise events and diurnal aspects of a limited set of statistical parameters and are combined into a single Noise Quality Index (NQI). This land-use regression based methodology is presented and will be illustrated with preliminary data explorations.

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1. Introduction

Noise annoyance and sleep disturbance due to traffic sources is recognized as a significant health and quality of life related issue [1,2,3]. The common scientific approach for health assessments is based on simulations of the noise exposure. Improving the propagation models and standardizing the results in a legal framework is a continuous process [4]. Despite all these efforts there are several weaknesses in the methodology. Community response and health effects on the individuals are a complex combination of multiple sources, contextual corrections and personal sensitivity. The most fundamental issue is the lack of sensitivity of the standardized noise indicators L_{den} and L_{night} indicators to subtle differences in the temporal structure of the noise exposure. An interesting approach to address the event-like structure in the noise exposure is found in the intermittence ratio (IR) [5]. Spatial features have their impact as well [6,7]. The uncertainties in traffic data are increased due to limitations of the calculation methods but even without these restrictions the spatial features influencing the subjective response cannot be taken into account. To illustrate this, a multinomial generalized additive model is applied to the SLO3 noise survey in Flanders (Belgium) [8]. Three covariates are included to illustrate the lack of explanatory power of L_{den} for the subjective response on a quality of life question (Figure 1).

People living close to a secondary or tertiary road as defined in the Open Street Map data (www.openstreetmap.org). have a higher annoyance response for similar L_{den} exposure levels over all categories. This is visualized by the higher annoyance response rate for short distance to secondary roads (second row in Figure 1). The spatial density of the buildings result in higher annoyance levels in open areas for annoyance response 4 and 5 (highly and extremely annoyed). The goal is to build an indicator that incorporates these features in the subjective response.

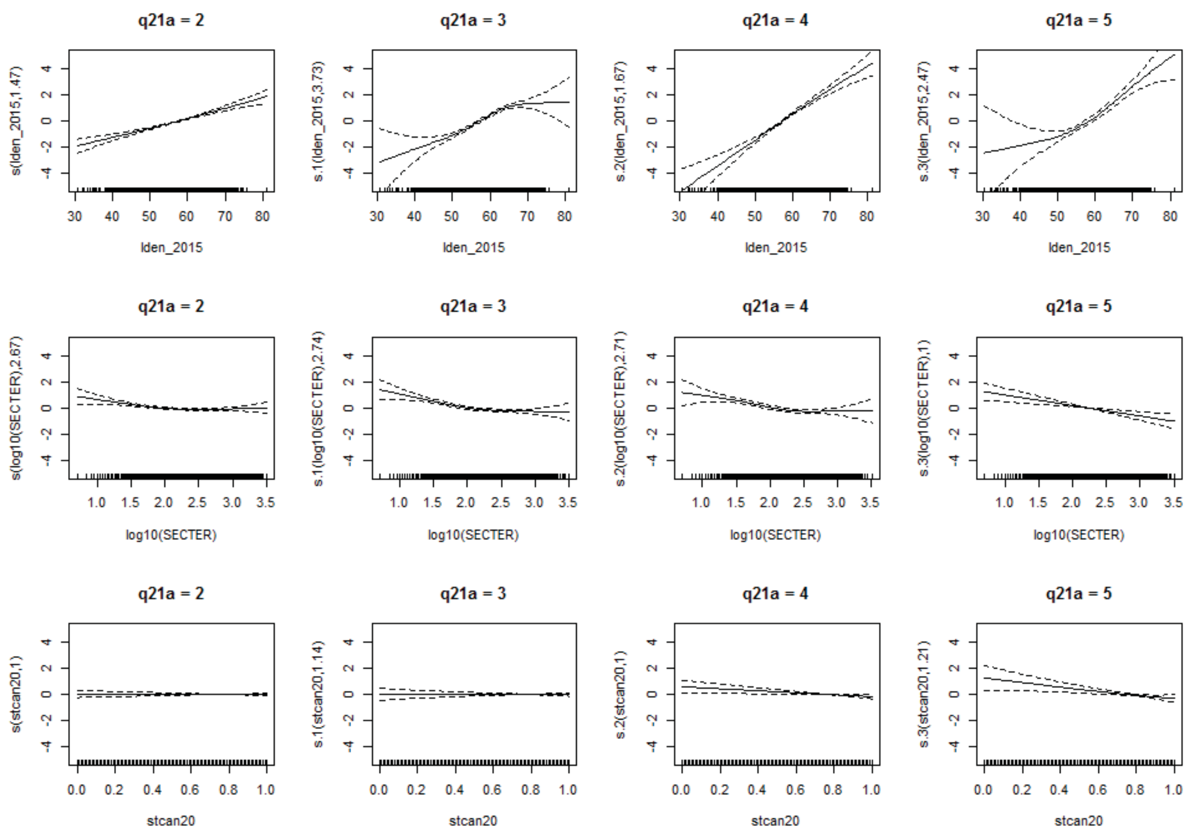

Figure 1. Multinomial generalized additive model (gam) for the QoL response (Q21a) in the SLO3 survey of the Flemish Government (2013). The response has five coregoties. The polynomial model estimates the occurrence of the responses relative to the reference (1= not annoyed) for each of the four other categories. with three covariates: L_{den}, log10 of distance to a secondary road and street canyon index (spatial measure of build-up area along the roads).

The temporal aspects have three main components. The short-term component is the impact of the individual events. The temporal component is the variability in the diurnal pattern. The actual duration of the quiet night period and the noise exposure in the sensitive periods of the night are expected to explain a significant portion of the interpersonal variation in the subjective responses.

The third level is the weekly pattern. Little knowledge is available on the effects of quiet days or night on a weekly level but it is already applied in practice for aircraft exposure. The weekly pattern is out of the scope of this paper. Temporal weekly patterns match the weekly activity pattern of the population and can affect the overall annoyance evaluation as well.

The fundamental problem is the quality of the underlying traffic data. The traffic data is not detailed enough to provide the temporal structure of the diurnal pattern. The systematic use of energy conserving noise map calculations reduces the sensitivity of the indicator for the diurnal pattern even further. In this paper we present an approach to use actual noise measurements as an alternative to the classical noise simulations. The aim is to build an indicator more sensitive to the diurnal pattern than L_{den} and $L_{night,}$ designed to include a higher explanatory quality of the response of the individuals in the noise surveys.

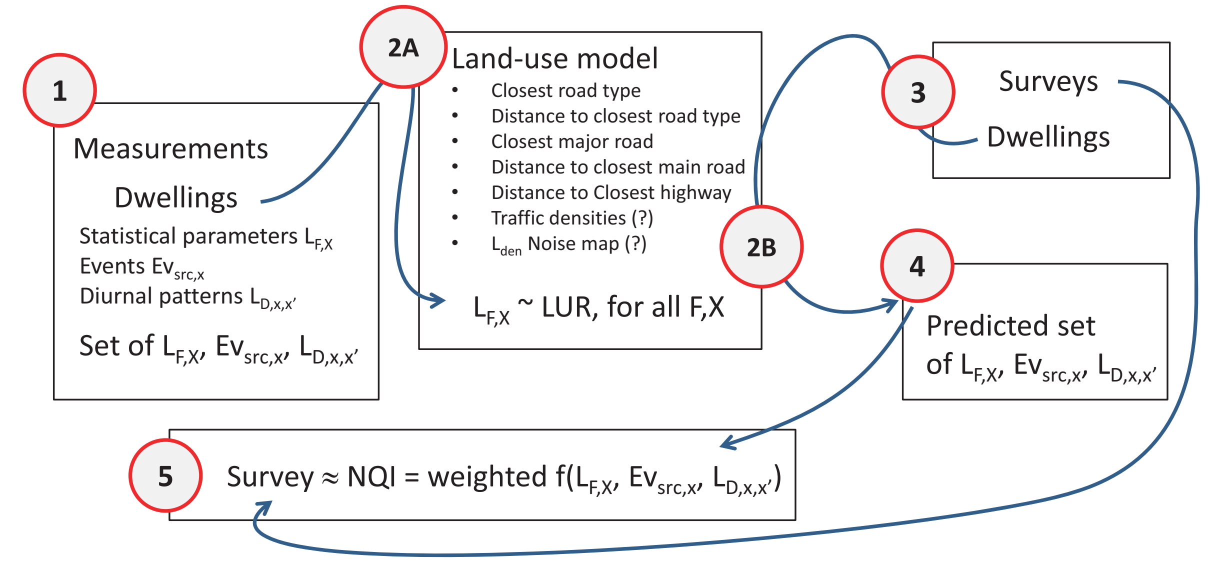

Figure 2. Step-wise process of matching noise measurement features to survey data through land-use regression techniques to build an alternative Noise quality Indicator (NQI).

This indicator is referred to as Noise Quality Index (NQI) for easy reference in this document . The NQI should outperform L_{den} in predicting the subjective response of the subjects in noise annoyance surveys. When replacing L_{den} by NQI in Figure 1, the spatial and temporal covariates should become insignificant.

2. Moving from simulations to noise measurements in QoL and health evaluations: Conceptual approach

In the physical forward scientific approach, noise measurements are sparsely included to validate the propagation models. The hardware and software costs of low quality noise measurements are decreasing and many monitoring solutions become available. Monitoring will never cover the entire spatial extent of an entire country or region but it is possible to perform measurements at the most typical situations. Spatial indicators can be used to extrapolate this information to a full spatial coverage. This practice is known as land-use regression (LUR).

The underlying hypothesis is that distinct statistical levels of a noise time series at a specific location are determined by a partially independent set of spatial and temporal attributes. Peak levels will be related to the distance to the closest road. The L_{A01} and L_{A05} will be indicators of the number of passages combined with the closest distance. L_{A95} will be an indicator of the distance to the closest traffic source with continuous traffic. The number of hours during the night with event-like traffic is an indication of the duration of the night, etc.

After predicting each of the relevant statistical levels to a location of interest, the NQI can be reconstituted out of its components for that chosen location. The second step is to define the structure of the NQI function. Each relevant noise feature will require an appropriate weight. This weight will be retrieved from a validation process based on the noise surveys. This step-wise process is illustrated in Figure 2.

Different questions have to be answered before starting this process:

1. Which temporal features in the time noise series will be preselected?
2. More measurements will imply more quality of the spatiotemporal models but the use of less standard noise features will reduce the available data. Do we aim for more measurements with less complex features or less measurements with more complex features?
3. Do we add other spatial attributes in the land-use regression models? It is tempting to add known spatial features related to soundscape or green spaces.
4. How do we determine the range of exposure situations? It is important to cover the full spectrum of exposure situations, including low exposure

locations. Since noise measurements are mainly performed when noise issues occur the typical available data might not cover the low exposure situations.

5. Noise related health effects are mediated by both annoyance and sleep disturbance. Can these two aspects be resolved with one indicator?

3. Preselection of the noise features

A pilot exploration of potential noise features is based on the UK Noise Incidence Study (NIS) [9]. 24 hour noise measurements are collected in 2000/2001 in England and Wales in 1020 locations. The data is available as hourly results for a small set of statistical levels (L_{A01}, L_{A10}, L_{A50}, L_{A90}, L_{A95}, L_{Aeq}, L_{Amax}). The GPS-locations are not made available due to privacy reasons. In parallel a Noise Annoyance Survey (NAS) is performed on a different set of the population and no spatial relation can be built between the two datasets [10]. This is a very typical situation. Measurement campaigns and annoyance assessments are not linked to each other. Significant funds resulted in two strong datasets but due to privacy limitations, the combined information cannot be linked nor explored. The presented approach is designed to overcome these methodological restrictions.

Table I. Not exhaustive set of diurnal parameters, available for all statistical levels .

Param	*Description*	*Hours*
Nstart	GoToSleep	22:00-23:59
Ndeep	Deep Sleep	00:00-03:59
Nend3h	Light Sleep	04:00-6:59
Nend1h	Awakening	06:00-06:59
MoRush	Peak exposure	07:00-08:59
…		

The large number of measurement sites gives the opportunity to explore the potential of an NQI function including all exposure situations. At this stage, we neglect the event-like noise features due to lack of data. A list of basic noise features are listed in Table I and visualized in Figure 3. Each of the window parameters can be applied to any statistical level L_X. Ultimately we want a NQI which is high for high quality living environments and low of low quality environments. In the basis set of noise features, low values are expected to be favourable but when including ranges over

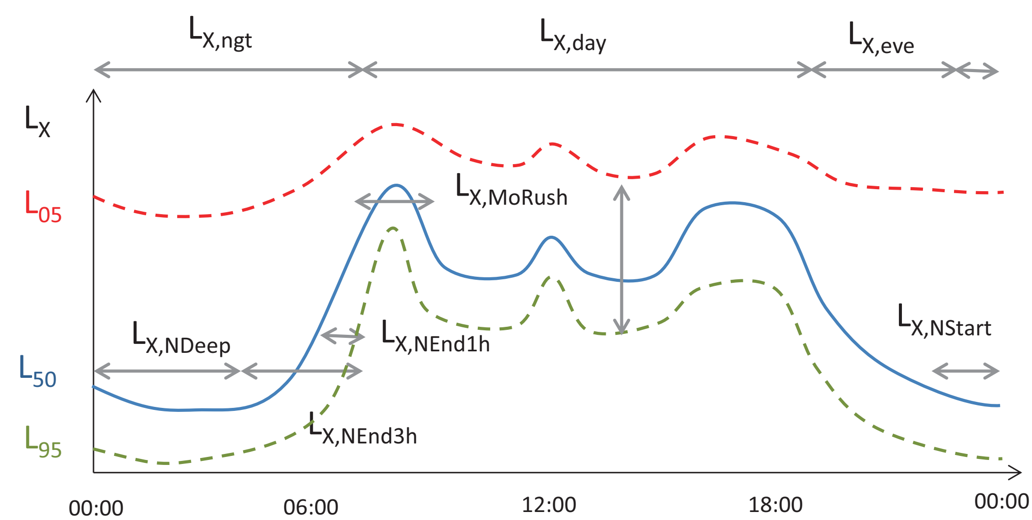

Figure 3. Visualization of the diurnal noise features. These features can be calculated for each statistical level. The NQI is a weighted combination of specific single noise features and differences between specific contrasting noise features.

$$NQI = norm(\sum_i w_i\, tr_i(L_{F,X_i}) + \sum_k w_k tr_k(Ev_k) + \sum_l w_l tr_l(L_{DD,l})) \quad (1)$$

specific periods and differences between the parameters for different statistical levels and periods, transformations of the results will be necessary. Physical features of the noise patterns expected to be relevant for the NQI can be preselected and transformed to a monotone function with high values indicating high quality and vice versa (see equation 1). In its most general form is will include basic statistical parameters ($L_{F,X}$), source/event specific parameters (Ev) and differences between the basic statistical parameters (L_{DD}). A literature study will provide external knowledge on potential parameters candidates.

More complex functions might be necessary but to improve the applicability of the NQI function in legislative contexts, a function matching intuitive characteristics is favourable.

4. Exploring an intuitive NQI on the UK Noise incidence database

accompanying presentation. On a regional scale we estimate that about one hundred measurement points will be necessary to build the LUR models.

5. Gathering of noise data for the land-use regression model

A region-wide land-use regression will have to include road traffic, rail traffic, industrial sites and air craft simultaneous. This requires the
Long measurements campaign on large sets of locations are not very common. In the field of industrial noise control engineering sparse data is available but these type of measurements are focussing of specific noise issues. Nevertheless these measurements are relevant since the industrial operations are not always dominating the noise climate. The impact of industrial sites on noise annoyance will be properly assessed in the land-use regressions if the spatial features of the industrial plants are included in the LUR model. The relative low exposed areas with only local traffic as a main noise source are much less sampled. The is an important limitation of the methodology. Additional efforts are required but this gap can be filled with cheap noise monitoring systems.

Table II. Basic and non-exhaustive list of potential parameters in the NQI

Parameter	*Weight*	*Motivation/Bimodal*
$L_{A95,NDeep}$	1.0	Lowest noise level during deep sleep
$L_{A95,NStart}$ - $L_{A95,NDeep}$	1.0	Difference in background during beginning and deep night
$L_{A01,NStart}$ - L_{A01_NDeep}	1.0	Difference in events during beginning and deep night
$L_{Aeq,Day}$ – $L_{A50,Day}$	1.0	Difference in L_{Aeq} and L_{50} during day (+ evening and night)
$L_{A01,Day}$ – $L_{A10,Day}$	1.0	Difference in L_{A01} and L_{A10} as a measure of cumulative events
$L_{A95,Day}$	1.0	Lowest noise level during day time

The noise measurement locations should include all possible variability in temporal structure and noise emission levels. An important feature of the NQI is the added information, not correlating with L_{den} but explanatory for the annoyance response.
In Table II a potential set of statistical parameters are listed. The basic transformation function is the relative ratio of the noise feature in the range of values for that feature. The range is clipped to the 1^{th} and 99^{th} percentile to be less sensitive to the extreme values in the noise data. Some features will be correlating and the optimization process will detect which features have the strongest explanatory power. It is expected that certain features will have bimodal or non-linear responses and other transformation functions might be necessary. A few explorative features of the correlation patterns will be presented in the

6. Conclusions

Noise measurements become more available and this added value can be exploited to improve the understanding of noise annoyance response. The noise measurement locations cover all relevant variability in the noise climates. Land-Use regression models extrapolate the basic noise features to the survey locations. A noise measurement based alternative for the L_{den} indicator Noise Quality Index can then be mapped to available noise surveys.

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