CONTRACT

iMonitraf!

TITLE 160818 B 01_03

Guidelines on the measurement of noise immissions along Alpine crossings

CLIENT

Dipartimento del territorio
Sezione della protezione dell'aria dell'acqua e del suolo
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PLACE AND DATE

Rivera, 10 April 2012

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1. Introduction

1.1. Structure of the report

This report is structured as follows:

Chapter 1 - Introduction and current legislative framework.

Chapter 2 - Projects, standards, directives, bibliographic references on which these guidelines are based.

Chapter 3 - Definitions used in the report.

Chapter 4 - Outline of the guidelines for the monitoring of road noise (RG) and outline of the guidelines for the monitoring of railway noise (RWG).

Chapter 5 - Description of the guidelines for the monitoring of road noise (RG).

Chapter 6 - Description of the guidelines for the monitoring of railway noise (RWG).

Chapter 7 - Support instruments and examples for the implementation of the guidelines.

1.2. Project description in the framework of the MONITRAF project

Within the framework of the interregional iMONITRAF! project (successor of MONITRAF 2005 - 2008), Canton Ticino has been entrusted with the task of presenting guidelines for measuring and protocoling noise immissions from road and railway traffic along the Alpine transit corridors.

The results of the MONITRAF project are the point of departure of this study. The MONITRAF partners have, in particular, identified 4 directions (see Fig. 1) to reduce Alpine freight traffic and its impact:

1. setting up a common monitoring system which would be a preparation for the other 3 directions, as it provides the needed data, and may thus become a kind of regional observatory;
2. adopting regional measures aiming at reducing regional / local peaks by way of bans (e.g. night time driving ban) or by reducing maximum speed limits;
3. introducing a common policy for modal split by internalising the external costs of road traffic and targeting support to the railway in order to improve service;
4. creating new measures such as the Alpine Crossing Exchange (as a complement to Direction 3).

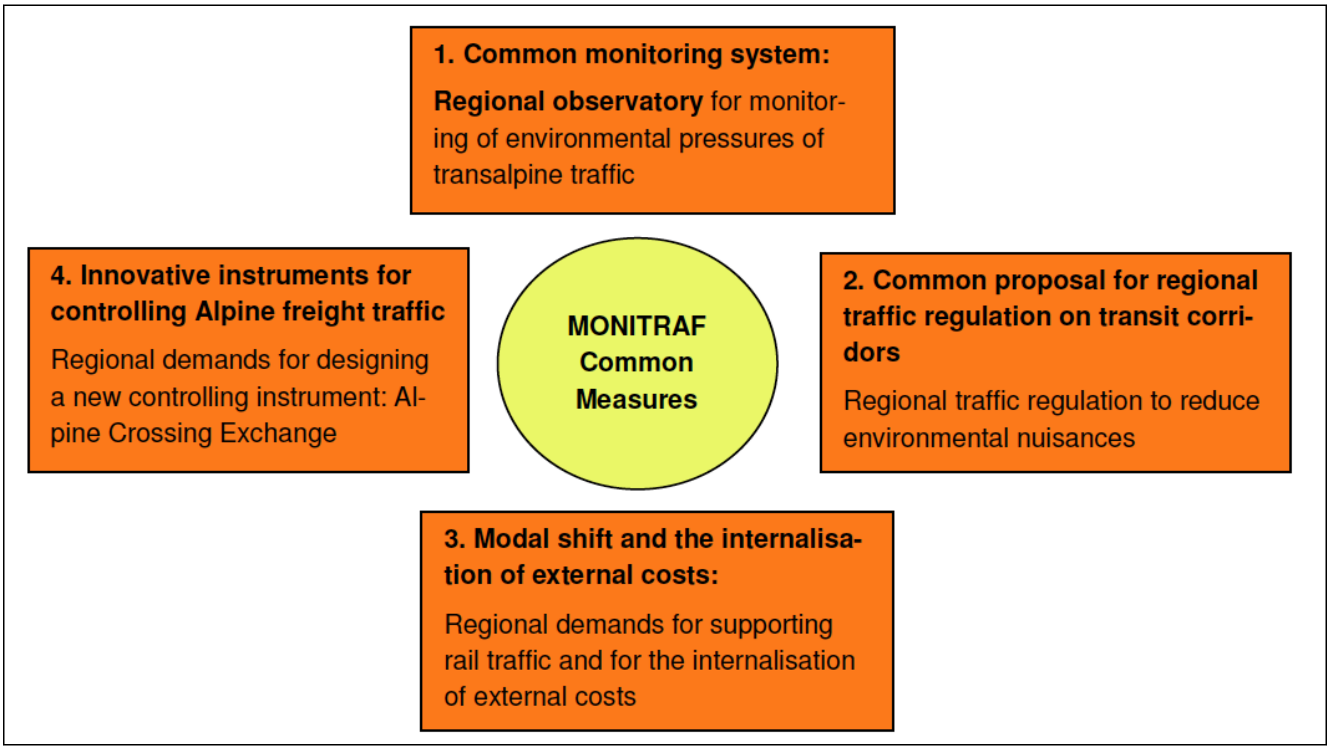

Figure 1: Schematic illustration of the 4 directions identified by the MONITRAF project

In order to evaluate the degree of sustainability of the present transport system, and as a means of contemplating future developments, MONITRAF has set out to define common indicators in collecting evidence on, and describing the 3 dimensions of, a sustainable transport system. In the Alpine countries, data has been collected on a large number of indicators, but at the moment there is no unanimously approved approach to measuring the sustainability of transport systems. The first step undertaken by the MONITRAF project has been to select a group of suitable indicators. The criteria to be met by these indicators were defined as follows:

1. to cover **not only the environmental aspects of traffic**, but also the social and economic ones;
2. to be precise and **scientifically valid**;
3. to be **politically acceptable and effective** with regard to already defined political objectives;
4. to be **technically feasible** (also in terms of costs);
5. to allow for **harmonization in data collection and use** in all MONITRAF regions in order to ensure that information may be compared on a consistent basis.

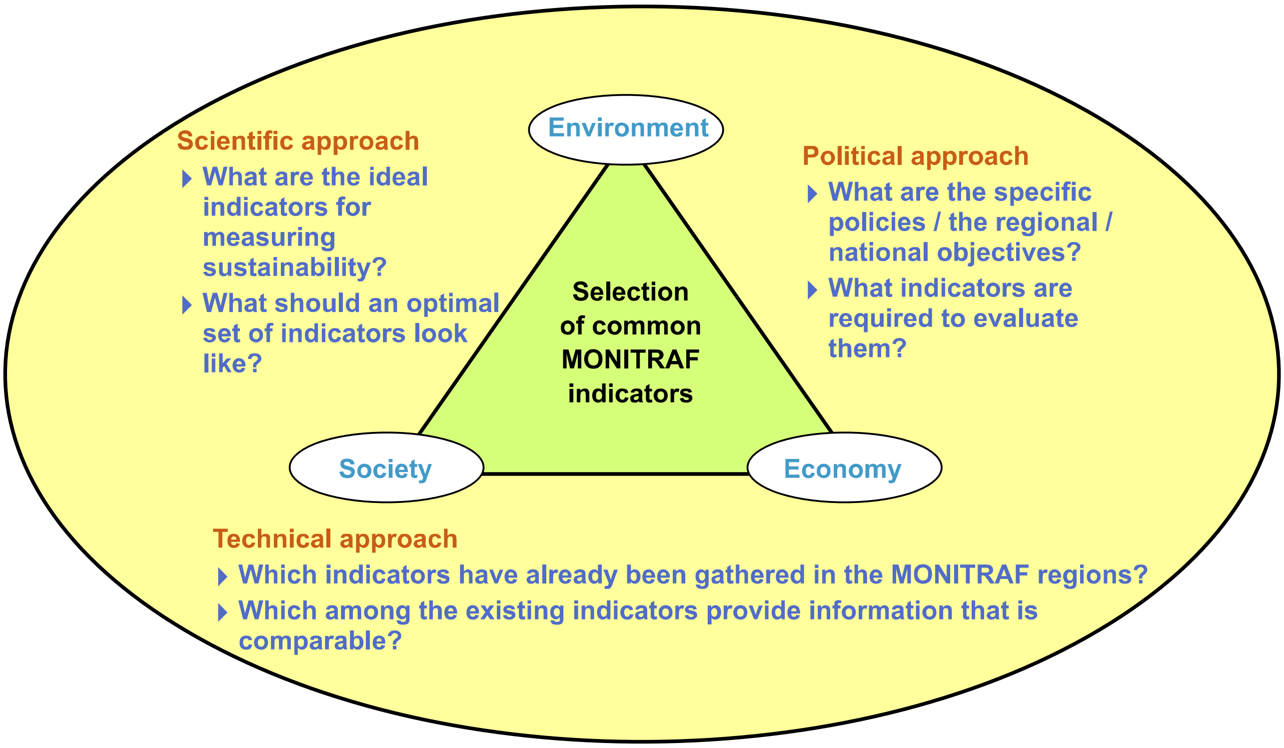

Figure 2: The MONITRAF approach for the selection of common indicators (Source MONITRAF 2007).

In defining the set of indicators, it became clear that all aspects of sustainability (see Fig. 2) had to be covered. In particular, monitoring was not to be limited to traffic flows and their impact, but rather extended to socio-economic factors. It was also clear that a **scientific** approach based on the definition of an ideal set of indicators for measuring sustainability was destined for failure. In fact, such an approach would have clashed with the need to *gather information from existing sources* (**technical** approach). A third intermediary approach between technical and scientific requirements turned out to be the **political** approach which called for major efforts in terms of indicators to monitor the various policies adopted at the regional and national levels.

The Monitraf project included a set of 25 indicators for the three aspects: environment, society and economy. At the beginning stage of the iMonitraf! project, the indicators which had been initially chosen were reviewed in order to simplify processes and ensure easier data retrieval. The indicators of the new iMonitraf! (see Table 1) put more emphasis on the environmental impact and on the assessment of population along cross-border corridors.

Nr.	Indicator	Main category	Data and definition
1	Road traffic fluxes	Traffic	Yearly average of mean daily traffic of light and heavy vehicles
2	Composition vehicle fleet	Traffic	Yearly percentage of vehicles referred to EURO classes in all heavy duty vehicles
3	Rail traffic fluxes	Traffic	Transalpine transport on rail: number of trains, tonnes carried and passengers
4	Air pollutant emissions by road traffic	Environment	Annual pollutant emissions evaluated for the transalpine road network stretches
5	Air concentrations measured	Environment	NO2, PM10 and PM2.5 concentrations on available stations in the project area
6	Noise assessment	Environment	Lden (noise indicator for overall annoyance) and Lnight (noise indicator for annoyance during the night period). Refer to the annex 1 of EU directive 2002/49/EC for detailed definition
7	Toll prices	Prices and regulation	Travel cost based on toll prices (highways and tunnels) per km for Euro 2 and Euro 5 Heavy duty vehicle (40 t, 5 axes) and a light vehicle.
8	Fuel prices	Prices and regulation	Yearly average of fuel prices (what the final consumer pays) on regional level (NUTS 2) and for country, distinguishing between diesel and petrol
9	GDP per inhabitant	Economy	Value of the economic performance resulting from productive activities in a period of reference
10	Population	Society	Inhabitants in a buffer of xxxx m along the corridors
11	Transport employments	Economy	Number of employed persons in the transport sector
12	Health impact	Quality of life	Studies on health impact assessments of transalpine traffic

Table 1: Set of common IMONITRAF! indicators. Noise-related indicators are highlighted in blue.

1.3. Swiss legislative framework

In Switzerland, the legislation pertaining to environmental noise is the Noise Abatement Ordinance (NAO) of 15 December 1986, an application of the Swiss Federal Environmental Protection Act of 7 October 1983. The objective of the Noise Abatement Ordinance is to protect the environment against "hazardous and disturbing noise", with reference to noise emissions from roads, railways, airports, shooting ranges, and facilities in the broadest sense (industrial, commercial, building servicing, etc.).

The indicator used to assess noise exposure is the **rating sound level L_r**, which is the sum of the average energy level, A-weighted and corrected as needed to take into account the specific noise (type, duration, pulse components and tonality components) in relation to its source. L_r must be further compared to limit values of noise exposure.

For the assessment of noise produced by vehicles and trains, a correction coefficient (K1 and K2 respectively) is applied to L_{eq}. For vehicles this coefficient depends on the traffic and is equal to "0" where the traffic exceeds 100 vehicles/hour. For trains, the correction coefficient is equal to -5.

The objectives of noise protection are defined by three different types of **exposure limits** (Table 2) which are established on the basis of the type of noise, the time of day, the use of the building and the area to be protected:

- **Planning values** are the most stringent, and apply to new facilities as well as the zoning and planning of new developable areas. These values are established on the basis of a precautionary principle.
- **Exposure limit values** represent the threshold at which one part of the population (15-25%) feels it is experiencing a disturbance, and they apply to existing facilities (prior to the NAO coming into effect).
- **Alarm values** are those values beyond which noise immissions can no longer be tolerated. These values are used to determine the urgency of noise control measures.

Sensitivity level	**Planning values L_r in dB(A)**		**Exposure limit values L_r in dB(A)**		**Alarm values L_r in dB(A)**	
	Day	Night	Day	Night	Day	Night
I	50	40	55	45	65	60
II	55	45	60	50	70	65
III	60	50	65	55	70	65
IV	65	55	70	60	75	70

Table 2 Noise exposure limits defined by the Swiss Noise Abatement Ordinance (NAO).

The time of the day or night during which the impact of noise is assessed depends on the type of noise being considered. For example:

Noise from road / railroad traffic		**Noise from industrial and commercial operations**	
Day	Night	Day	Night
6:00-22:00	22:00-6:00	7:00-19:00	19:00-7:00

Table 3 Breakdown of the daily assessment period on the basis of the source of noise, in conformity with the Swiss Noise Abatement Ordinance (NAO).

A higher level of noise can be tolerated during the **day** than at **night**. Distinctions are also made on the basis of the noise zoning at the immission point. The following levels have been defined:

- The **rating sound level L_r**, *based on the measured or calculated L_{Aeq}* and on correction values which are specific to the source and which quantify the disturbance.
- The **sensitivity levels** for each land-use zone (noise zoning). These are reported on the development plans, and indicate the area's vulnerability to noise on the basis of land-use (residential, commercial, …). A different exposure limit is applied to each sensitivity level. The

more sensitive to noise the area's components are, the lower the levels to conform to. The NAO laid down four levels of sensitivity:

... Sensitivity level I, typical of natural leisure and recreational areas, with the most stringent requirements;

... Sensitivity level II, for residential areas;

... Sensitivity level III, which normally characterizes commercial, agricultural and mixed areas;

... Sensitivity level IV, typical of industrial areas with a high level of noise, and the least stringent limit values.

1.4. Italian legislative framework

The Prime Ministerial Decree (DPCM 01/03/1991) and subsequently the Framework Law on Noise Pollution (L. 447/1995) and its related decrees (DPCM 14/11/1997, DPCM 16/03/1998 etc.) all make use of the equivalent continuous A-weighted sound pressure level to verify compliance with lawful maximum noise exposure values. With respect to the Swiss legislation, the assessment level has not been defined, although it is stated that the maximum level of noise produced by stationary and mobile sources must be compared with the following indicators:

- emission limit values (measured near the noise source in areas used by people or communities);
- immission limit values (measured near the receivers) and which may be: absolute (global noise immissions in the external environment by all noise sources) or differential (noise immissions in a housing environment and based on the differential criterion according to which the difference between environmental noise and residual noise should not exceed 5 dB(A) during the day and 3 dB(A) at night). The Prime Ministerial Decree DPCM 14/11/1997 specifies cases in which this criterion is not applicable;
- quality values (to be attained in the short, medium and long term with presently available improvement methodologies and technologies);
- attention values (which indicate a potential health hazard for people and for the environment, and beyond which a noise mitigation plan must be drafted).

In Italy as well, noise limit values are established on the basis of a sound categorisation with municipal areas being classified under the various categories listed in Table 4.

Land use category		**Time reference**					
		Day 06 -22			**Night 22 - 06**		
		Em	Im	Qu	Em	Im	Qu
I	Particularly protected areas	45	50	47	35	40	37
II	Predominantly residential areas	50	55	52	40	45	42
III	Mixed areas	55	60	57	45	50	47
IV	Areas with intensive human activity	60	65	62	50	55	52
V	Predominantly industrial areas	65	70	67	55	60	57
VI	Exclusively industrial areas	65	70	70	65	70	70

Table 4 Noise values defined by DPCM 14/11/1997 on determining limit values of noise sources (Em = emissione limit values, Im = absolute immission limit values, Qu = quality values).

The criteria for establishing attention values are laid down in Table 5.

For all land use categories	Time reference	
	Day (06-22)	**Night (22-06)**
if applied to one hour	Absolute immission values increased by 10 dB(A)	Absolute immission values increased by 5 dB(A)
if applied to the entire reference period	Absolute immission values	Absolute immission values
Note: Attention values do not apply to land strips which fall within the competence of road, railway, maritime and airport infrastructures.		

Table 5 Attention values referred to in Art. 6 DPCM 14/11/1997

Moreover, it is important to specify that absolute immission and emission limit values for individual transport infrastructure within their respective noise-relevant land strips as well as their extension are laid down in applicable implementing decrees. For receivers within the relevant noise land strips of transport infrastructure, there is a two-fold constrain:

- for overall noise produced by all sources other than those related to transport infrastructure, the absolute immission limit values derived from the noise categorisation apply;
- for noise produced by specific means transport (road, railway, projections on the ground of an aircraft's path in the sky) the absolute immission limit values are set by the corresponding implementing decree, notably:
  - for road noise, **DPR no. 142 of 30/03/04** (cf. Table 6) which sets different noise-relevant land strips and more stringent limit values for newly built roads;
  - for railways, **DPR no. 459 of 18/11/98** (cf. Tables 7 and 8);
  - for airport noise, **DMA 31/10/97**.

<table>
<tr><th rowspan="3">TYPE OF ROAD
(as defined by the Italian Highway Code)</th><th rowspan="3">SUB-TYPES FOR NOISE DEFINING PURPOSES
(CNR 1980 standards and PUT directives)</th><th colspan="6">All receivers</th><th colspan="3">Schools (day limit only), hospitals, rest/nursing homes</th></tr>
<tr><th rowspan="2">Width of the noise-relevant land strip (m from the edge of the road)</th><th colspan="2">Limit values</th><th rowspan="2">Width of the noise-relevant land strip (m from the edge of the road)</th><th colspan="2">Limit values</th><th rowspan="2">Width of the noise-relevant land strip (m from the edge of the road)</th><th colspan="2">Limit values</th></tr>
<tr><th>Day dB(A)</th><th>Night dB(A)</th><th>Day dB(A)</th><th>Night dB(A)</th><th>Day dB(A)</th><th>Night dB(A)</th></tr>
<tr><td>A
motorway</td><td></td><td>0-100 (strip A)</td><td>70</td><td>60</td><td>100-250 (strip B)</td><td>65</td><td>55</td><td>0-250 strip A+B)</td><td rowspan="6">50</td><td rowspan="6">40</td></tr>
<tr><td>B
extra-urban main road</td><td></td><td>0-100 (strip A)</td><td>70</td><td>60</td><td>100-250 (strip B)</td><td>65</td><td>55</td><td>0-250 strip A+B)</td></tr>
<tr><td rowspan="2">C
extra-urban secondary road</td><td>C_a</td><td>0-100 (strip A)</td><td>70</td><td>60</td><td>100-250 (strip B)</td><td>65</td><td>55</td><td>0-250 strip A+B)</td></tr>
<tr><td>C_b</td><td>0-100 (strip A)</td><td>70</td><td>60</td><td>100-150 (strip B)</td><td>65</td><td>55</td><td>0-150 strip A+B)</td></tr>
<tr><td rowspan="2">D
fast urban road</td><td>D_a</td><td>0-100</td><td>70</td><td>60</td><td rowspan="4" colspan="3"></td><td>0-100</td></tr>
<tr><td>D_b</td><td>0-100</td><td>65</td><td>55</td><td>0-100</td></tr>
<tr><td>E
urban district road</td><td></td><td>0-30</td><td rowspan="2" colspan="2">Defined by municipalities in conformity with noise zoning</td><td>0-30</td><td rowspan="2" colspan="2">Defined by municipalities in conformity with noise zoning</td></tr>
<tr><td>F
local road</td><td></td><td>0-30</td><td>0-30</td></tr>
</table>

Table 6 Noise relevant land strips and limit values set by DPR 142/04 for existing roads and similar

	Land strip A 0 - 100 m from the centre line of external rails for each side			Land strip B 100 - 250 m from the centre line of external rails for each side		
	Hospitals, rest and nursing homes	Schools	All other receivers	Hospitals, rest and nursing homes	Schools	All other receivers
Limit values - day (06h-22h)	50 dB(A)	50 dB(A)	70 dB(A)	50 dB(A)	50 dB(A)	65 dB(A)
Limit values - night (22h-06h)	40 dB(A)	-	60 dB(A)	40 dB(A)	-	55 dB(A)

Table 7 Noise relevant land strips and limit values established by DPR 459/98 for existing railways and new railways with project speeds not exceeding 200 km/h

	Noise relevant land strip 0 - 250 m from the centre line of external rails for each side		
	Hospitals, rest and nursing homes	Schools	All other receivers
Limit values – day (06h-22h)	50 dB(A)	50 dB(A)	65 dB(A)
Limit values – night (22h-06h)	40 dB(A)	-	55 dB(A)

Table 8 Noise relevant land strips and limit values established by DPR 459/98 for new railways with project speeds above 200 km/h

1.5. European legislative framework

The scenario is slightly different at the European level. In 1996, following the publication of the European Commission's Green Paper on future noise policy, Directive 2002/49/EC, also known as the Environmental Noise Directive (END), was issued. This directive on the assessment and management of environmental noise defines an approach which aims to avoid, prevent or reduce the harmful effects due to the exposure to environmental noise, excluding that generated by the exposed persons themselves, noise from domestic activities, noise created by neighbours and noise at work places.

The indicators used, L_{den} and L_{night}, are both based on L_{Aeq} and are defined as follows:

- L_{den} is the indicator of potential overall annoyance for the general population over a period of 24 hours. It is calculated as the sum of L_{Aeq} levels during the day (L_{day} over 12 hours, 7:00-19:00), evening ($L_{evening}$ over 4 hours, 19:00-23:00) and at night (L_{night} over 8 hours, 23:00-7:00);
- L_{night}, as defined above, is used to assess sleep disturbance and coincides with L_{Aeq} for night-time hours without any penalty.

The time periods described above apply to all types of noises. The values of both indicators must be representative of exposure on a yearly basis and, in urban agglomerations, they must be assessed separately for each type of noise source.

Exposure limits may vary depending on the type of noise, as well as the surrounding environment and the different noise sensitivity levels of people.

In Italy, the legislative decree 194/2005 formally acknowledges the European directive 2002/49/CE. The Italian legislation used to be different, notably in terms of noise indicators. The UNI 11252:2007 standard was therefore issued to define conversion procedures for day and night L_{Aeq} and LVA[1] into L_{den} and L_{night} indicators. Legislative decree 194/2005 defines the time periods as follows:

1) day: from 06.00 to 20.00;
2) evening: from 20.00 to 22.00;
3) night: from 22.00 to 06.00.

[1] Rating sound level for airport noise.

2. Basis

2.1. Projects, norms and directives CH and EU

[1] 2002/49/CE: Environmental Noise Directive, 25.06.2002;

[2] 2003/613/CE, Raccomandazione della Commissione del 6 agosto 2003;

[3] EN ISO 11819-1: Messung des Einflusses von Strassenoberflächen auf Verkehrsgeräusche. Teil 1: Statistisches Vorbeifahrtverfahren, Mai 2002

[4] Leitfaden Strassenlärm – Vollzugshilfe für die Sanierung, ASTRA und BAFU, Dezember 2006

[5] Technisches Merkblatt für akustische Belagsgütemessungen an Strassen, Leitfaden Strassenlärm - Anhang 1c, ASTRA und BAFU, Dezember 2006

[6] Monitoring flankierende Massnahmen Umwelt (MfM-U), Bundesamt für Umwelt (BAFU), 2004 - Heute

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[8] Bundesgesetz über die Lärmsanierung der Eisenbahnen (742.144), 24.03.2000

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[10] Harmonoise: Definition of Track Influence: Roughness in Rolling Noise, 17.7.2003 (www.imagine-project.org)

[11] Method for measuring the influence of road surface on traffic noise – part 2: «The CloseProximity method», ISO/CD-11819–2

[12] Railway applications – Acoustics – Measurement of noise emitted by railbound vehicles, ISO 3095, 2005

2.2. References

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[17] IFEC Consulenze SA, 170323 E 07 Pavimentazioni a bassa emissività acustica, Presentazione finale, 16.02.2007

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[22] Robert Attinger, Monitoring railway noise in Switzerland from 2003 to 2010, RTR 3, 2010

3. Abbreviations and Definitions

Abbreviation	Definition	Remark
p	Sound pressure in Pa	Fluctuating pressure superimposed on the static pressure in the presence of sound
L	Sound pressure level in dB	Level in decibels calculated with the equation $L = 10 \cdot \log(p/p_0)^2$, dove p_0 = 20 µPa;
L_A	A-weighted sound pressure level in dB(A)	Sound pressure level obtained by using the frequency weighting A-filter, in A-decibels
L_{AF}	AF-weighted sound pressure level in dB(A)	Sound pressure level obtained by using the frequency weighting A-filter with F (Fast) time weighting, in decibels
L_{AFmax}	Maximum AF-weighted sound pressure level in dB(A)	Maximum value of the AF-weighted sound pressure level
L_{Aeq}	Equivalent A-weighted sound pressure level in dB(A)	Energetic average of the A-weighted sound level measured during a time internal T (e.g. duration of the event)
$L_{Aeq,1s}$	A-weighted exposure level in dB(A)	Energetic average of the sound level of a single event measured during a time interval T and normalised to 1 second
L_{day}	Day-noise indicator	A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the day periods (07:00-19:00) of a year
$L_{evening}$	Evening-noise indicator	A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening periods (19:00-23:00) of a year
L_{night}	Night-noise indicator	A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods (23:00-07:00) of a year
VL	Light vehicles	Light vehicles with 4 wheels
VP	Heavy vehicles	Heavy vehicles with at least 2 axles and more than 4 wheels
SEM	Sampling-Emissions-Measurements	Emission of mixed traffic on the whole section of the road with separate traffic count for the various lanes
SPB	Statistical Pass-By	Emission of a single passage. Thanks to the analysis of a large number of passages it is possible to determine the levels of sound emissions of the various categories of vehicles travelling on one lane.
SEL	Sound exposure level in dB(A)	Sound exposure level obtained by “focusing” the energy of one event into 1 sec.
TEL	Transit exposure level in dB(A)	Sound exposure level during one passage.

Table 9 List of abbreviations and definitions

4. Guidelines

4.1. Guidelines for monitoring road noise

RG1 Goal

1 The goal of these guidelines is to obtain data for establishing road noise indicators that are representative, homogeneous and comparable, that can adapt to the evolution of this phenomenon over time. Of paramount importance is the characterisation of the noise emission.

RG2 Location of monitoring points

2 Road traffic must be monitored at sample points that are representative of the noise emission, with particular reference to the composition of traffic, speed, gradient and road surface.

3 The microphone must be positioned at a distance of 20 m from the middle of the road and 4 m above its surface.

4 The area around the microphone must be free of obstacles (80 m for main roads and 130 m for motorways).

5 If a guardrail or any other obstacle can potentially influence the propagation of sound, the microphone should be placed higher.

RG3 Duration and frequency of measurements

6 Inasmuch as possible, a measurement campaign shall last *2 weeks (minimum of a few days)*.

7 During the measurement campaign, periods of "intensive" measurements must be arranged, representing brief intervals lasting a minimum of *30 minutes*, yet sufficient to ensure the measurement of at least *1000 vehicles*. During this time, some parameters are to be surveyed with greater precision (cf. points 10 and 11).

8 Measurements are repeated 4 times over a one-year period.

RG4 Data collection

9 Data on the characteristics of the infrastructure being monitored must be gathered at the point of measurement, and shall consist of the following:

- type of road cover;
- year the road was paved;
- road slope;
- maximum speed allowed;
- maps and photographic documentation.

10 The noise must be characterized through the acquisition of the following data on a continuous basis (*half-hourly averages*):

- L_{Aeq};
- L_{max}, L_{min}, L_5, L_{10}, L_{50}, L_{90}, L_{95}, L_{99};
- Third octave band sound spectrum.

11 Traffic conditions must be described through the acquisition of the following values on a *half-hourly* basis:

- total number of vehicles;
- for dual carriageways, the number of light and heavy vehicles travelling in each direction;

- number of light and heavy vehicles in each lane during “intensive” measurement periods;
- average speed of light and heavy vehicles during “intensive” measurement periods.

12 To characterise weather conditions, the following data must be collected:

- air temperature;
- precipitation;
- wind speed;
- temperature of the road during periods of “intensive” measurements.

13 Exposure levels (at 20 m distance and 4 m height) will be calculated on the basis of traffic data, as well as the difference between the measured value and the value obtained with ISO 9613 algorithms.

RG5 Calculating noise indicators

14 The day-evening-night level is calculated on the basis of half-hourly equivalent level data measured over a one-year period:

$$L_{den} = 10 \cdot \log\left(\frac{12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}}}{24}\right),$$

where:

L_{day} (day-noise indicator) is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the day periods (07:00-19:00) of a year;

$L_{evening}$ (evening noise indicator) is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening periods (19:00-23.00) of a year;

L_{night} (night-time noise indicator) is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods (23:00-07:00) of a year.

15 The night-time noise indicator is calculated on the basis of half-hourly equivalent level data measured over a one year period.

$$L_{night},$$

where night means an 8 hour interval as defined under point 14.

RG6 Characterising the road surface

16 Measurements of road surface noise shall be carried out periodically by means of the SPB method (spot measurement) following ISO 11819-1 (Acoustic-measurements of the influence of road surfaces on traffic noise - Part 1, Statistical Pass-By Method, 1997) and possibly with the CPX (“trolley” method) in accordance with ISO/CD 11819-2 (measurement that is extendible to a long stretch).

RG7 Minimum specifications for measuring instruments

17 The noise measurement chain shall comply to current Class 1 EN standards (cf. “IEC 61672 Electroacoustics - sound level meters, 2002"). **Sound level meters** shall have the following characteristics:

- frequency range **between 20 Hz and 10 kHz**, with a minimum sampling speed of 22 kHz;
- dynamic range **between 40 and 110 dB(A)**.

The microphones shall be suitable for outdoor use and protected against rain, snow and wind by means of a suited cover.

18 Weather stations shall be equipped to measure the following parameters:

- air temperature and road surface temperature (for “intensive” measurement intervals);
- quantity of precipitation;
- wind speed.

19 Traffic counters shall be designed to ensure:

- the measurement of traffic in both directions;
- the categorisation of vehicle classes;
- the measurement of vehicle speed.

RG8 Calibration

20 Prior to and at the end of every measuring campaign, all the components of the noise measuring chain must be checked manually at least once for correct response using a Class 1 acoustical calibrator as per IEC 942.

21 In the event of a negative outcome of a calibration check, all data recorded after the last positive check shall be disregarded.

22 Automatic verification methods are also admissible for checking the smooth operation of the equipment. In this case, data recorded prior to a malfunction may be considered as valid only if the time when the malfunction first occurred can be determined with sufficient certainty.

23 The various authorities in charge shall meet periodically to carry out comparative campaigns (ring calibration).

RG9 Validation of collected data on noise levels

24 Checks carried out during the assessment procedure of the time profiles of sound levels shall allow to identify

- measurements of noise levels affected by noisy atmospheric events such as storms, heavy rain and strong winds;
- intervals during which crossborder traffic on the road infrastructure was interrupted due to occasional occurrences;
- significant changes in the L_{Aeq} time profile.

25 In the case of significant changes in noise levels as a result of events unrelated to vehicular traffic, as for example noisy atmospheric events, these must be reported and the acquired data shall not be considered valid and shall therefore not be used for subsequent analyses.

RG10 Data management

26 Sound level data complemented by descriptive data on the location will be fed into a specific database ("iNoise"). To this purpose, upon completion of the measuring campaign, the authorities in charge shall provide the appropriate data in an Excel file (one for each measurement location) where the format of the filename will be as follows:

DATI_FONOMETRICI_Strade_Nomevalico_#.xls
(i.e. SOUND_LEVEL_DATA_Road_AlpineCrossing_#.xls)

where "#" is a progressive number.

4.2. Guidelines for railway noise monitoring

RWG1 Goal

1 The goal of these guidelines is to obtain data for establishing railway noise indicators that are representative, homogeneous and comparable, and that can adapt to the evolution of this phenomenon over time. Of paramount importance is the characterisation of noise emissions.

RWG2 Location of monitoring points

2 The rail system must be monitored at various sample points that are representative of typical noise emissions, referencing to the speed and the length of trains as well as their composition. The roughness of the rails must comply with the ISO 3095 (2005) standard [12].

3 For the correct identification of single events, the measurement point must be selected so as to ensure that the residual sound level is at least 10 dB(A) below L_{AFmax} values.

4 The microphone shall be positioned at a point 7.5 m from the centre line of the track, and at a height of 1.2 m above the rail.

RWG3 Duration and frequency of measurements

5 Inasmuch as possible, a measurement campaign shall last *2 weeks (or, at the minimum, a few days).*

6 Measurements shall be repeated 4 times over a period of one year.

RWG4 Data collection

7 Data on the characteristics of the rail infrastructure being monitored shall be gathered at the point of measurement, and shall consist of the following:

- type of track;
- type of sleepers (concrete, wood, steel, …);
- maps and photographic documentation.

8 The measurement of noise levels is activated when a preset threshold is passed and is effected with a FAST time constant so as to determine:

- the start time t_1 (hh:mm:ss), when the train enters the measurement zone;
- the end time t_2 (hh:mm:ss), when the train exits the measurement zone;
- the duration T_p (s) of the event;
- the time profile $L_{AF}(t)$ of the single transit;
- the sound exposure level of the single event (SEL in dB(A));
- the sound exposure level of the single transit (transit exposure level, TEL in dB(A));
- the third octave band sound spectrum.

9 Trains must be identified and described according to the following attributes:

- type (passenger, freight, service or undefined);
- speed (km/h);
- length (m).

10 The following data must be collected for the characterisation of weather conditions:

- air temperature;
- quantity of precipitation;
- wind speed.

RWG5 Calculating noise indicators

11 The L_{day} $L_{evening}$ and L_{night} parameters are calculated on the basis of the sound exposure levels of the single events SEL_i (where i represents a single train), with the following formula:

$$L_{day},\ L_{evening},\ L_{night} = 10 \cdot \log\left(\sum_i 10^{\frac{SEL_i}{10}}\right) - 10 \cdot \log(T/1s)\ ,$$

where the sum comprises all trains which transited over the various time periods: day (07:00-19:00, T = 43200 s), evening (19:00-23:00, T = 14400 s) and night (23:00-07:00, T = 28800 s).

12 On the basis of L_{day}, $L_{evening}$ and L_{night}, the day-evening-night level is calculated as follows:

$$L_{den} = 10 \cdot \log\left(\frac{12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}}}{24}\right).$$

RWG6 Characterising the tracks

13 The roughness of the rails at the measurement point shall be measured periodically in accordance with ISO 3095 (2005) [12].

RWG7 Minimum specifications for measuring instruments

14 The noise measuring chain shall comply with current Class 1 EN standards (cf. “IEC 61672 Electroacoustics - sound level meters, 2002"). **Sound level meters** shall have the following characteristics:

- frequency range **between 20 Hz and 10 kHz**, with a minimum sampling speed of 22 kHz;
- dynamic range **between 40 and 110 dB(A)**.

15 Weather stations shall be equipped to measure the following parameters:

- air temperature;
- quantity of precipitation.

16 The characterisation of trains may be effected with axle counters to determine

- the train’s speed;
- the number of axles;
- the type of train.

Alternatively, trains may be identified by requesting the administrator of the railway being monitored for the transit schedules.

RWG8 Calibration

17 Prior to and at the end of every measuring campaign, all the components of the noise measuring chain must be checked manually at least once for correct response using a Class 1 acoustical calibrator as per IEC 942.

18 In the event of a negative outcome of a calibration check, all data recorded after the last positive check shall be disregarded.

19 Automatic verification methods are also admissible for checking the smooth operation of the equipment. In this case, data recorded prior to a malfunction may be considered as valid only if the time when the malfunction first occurred can be determined with sufficient certainty.

20 The various authorities in charge shall meet periodically to carry out comparative campaigns (ring calibration).

RWG9 Validation of collected data on sound levels

21 Checks carried out during the assessment procedure of the time profiles of sound levels shall allow to identify the following

- sound events which are not attributable to transiting trains or which are incidental;
- sound events which may be affected by noisy weather such as storms, heavy rain and strong wind.

22 For the validity of the L_{Aeq} value in the reference period (day/evening/night), the number of invalidated train transits due to miscellaneous noise events must not exceed 10% of the total number of transits.

RWG10 Data management

23 At the end of each monitoring campaign, the measured data shall be collected in specially designed Excel spreadsheets. The first file shall contain the basic data of individual passages, with one file for each passage. The format of each filename shall be:

DATI_FONOMETRICI_BASE_Ferrovie_Nomevalico_#.xls
(i.e. BASE_SOUND_LEVEL_DATA_Railway_AlpineCrossing_#.xls)

where "#" is a progressive number.

The resulting data from each Excel file shall be consolidated into a summary file for each point of measurement where the format of the filename shall be:

DATI_FONOMETRICI_SOMMARIO_Ferrovie_Nomevalico_#.xls
(i.e. SOUND_LEVEL_DATA_SUMMERY_Railway_AlpineCrossing_#.xls)

where "#" is a progressive number.

5. Development of guidelines for monitoring road noise

These guidelines for the monitoring of road noise are divided into 10 main chapters, each comprising several ciphers. The various chapters are described hereunder.

5.1. Goal of the guidelines

The goal of these guidelines for monitoring noise along Alpine corridors directly depends on the objectives being pursued. As illustrated in Figure 3, a distinction is generally made between strategic objectives directly linked to the motivation behind the monitoring and the operational objectives which are functional to the fulfilment of the former and more closely related to the modes of monitoring.

The strategic objectives must be connected with the directions (2, 3 and 4) which were identified by the MONITRAF project. Their aim is more specifically to verify the effectiveness of policies common to the various transit corridors as well as of regional policies which are specific to one corridor. The central quantity is the equivalent continuous pressure level (L_{eq}). In fact, this represents an indicator of noise emission and may be used to describe the evolution of noise originating from a single source. When coupled with other information such as

- traffic intensity;
- traffic composition (% HV);
- deterioration (or renewal) of the road surface;
- weather conditions (cf., for ex. rain);
- evolution of vehicles;
- …

it becomes possible to identify the cause of change, and therefore to verify the effectiveness of the various policies.

L_{eq} also serves, after appropriate renormalisation, as an emission level in mathematical models used in calculations of noise immissions.

For all of these reasons, these guidelines aim at obtaining road noise indicators that are representative, homogeneous and comparable. This may be achieved by setting a range of operational objectives. These objectives are discussed in the remaining points of these guidelines, and are intended to answer the following questions:

- What?
- Where?
- How?
- When?

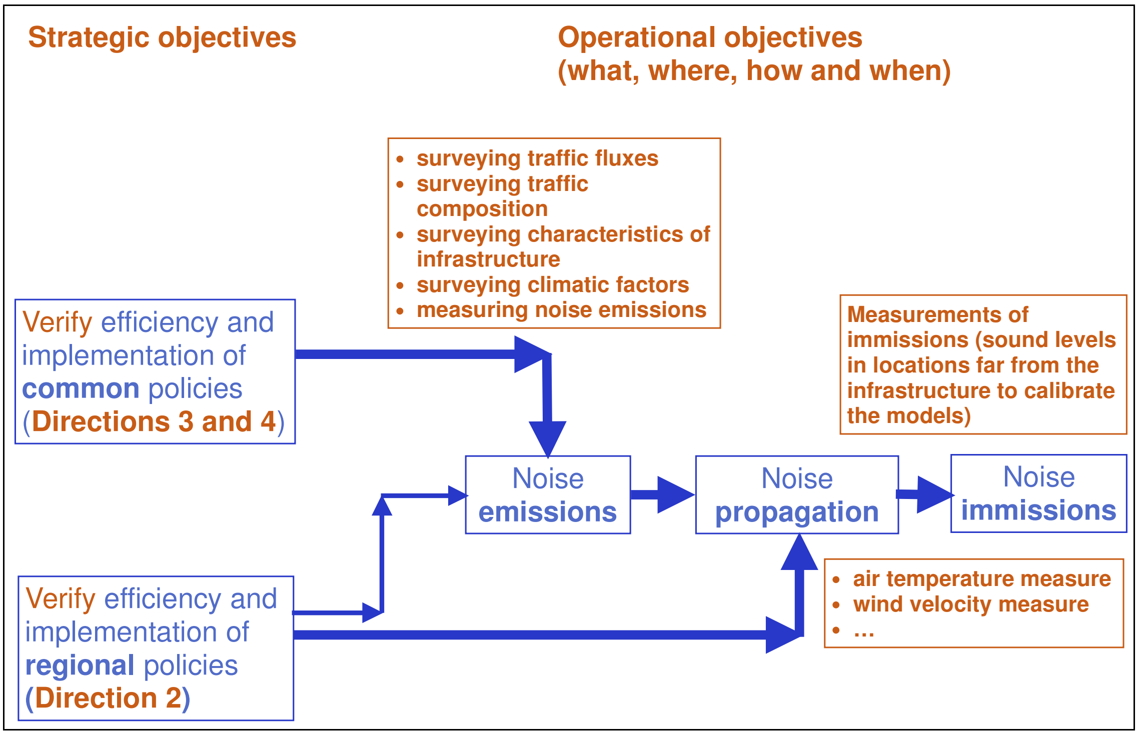


Figure 3: Objectives of noise monitoring along Alpine transit roads.

5.2. Location of monitoring points

This chapter deals with two fundamental aspects: the criteria for determining the choice of monitoring points along the main roads, and the (geometrical) requirements which need to be complied with when positioning microphones.

5.2.1. Selecting the measurement location along the road

In order to obtain *valid, representative and reproducible* data, the measurement points must be selected with great care. The criteria presented hereunder are based on experience, and their application allows for the comparison of the data measured at various locations.

In particular, **2 selection levels** are being proposed: **level one**, a general level which allows the identification of **acoustically homogeneous stretches** representative of several traffic corridors with regard to

- number of vehicles,
- speed,
- gradient and
- type of road surface,

and **level two**, which allows the identification of measurement points within the stretches on the basis of **quality requirements of (rough) data**. In this regard, care must be taken that

- the road surface is in good condition,
- the speed of vehicles is constant (so as to avoid those places where lane changes are common);
- traffic on this road is the only source of noise (no other noise);
- accessibility to the power supply is guaranteed;
- there is sufficient space on the edge of the road to position the microphone.

5.2.2. Location of a road-side microphone

In general, the proposed measurements follow the SEM (random Sampling-Emissions-Measurement) method. This (non-standardized) method measures the emission of mixed traffic on the entire road section. To this purpose, the microphone must be positioned at a distance of 20 m from the middle of the road and at a height of 4 m above the road surface (cf. Figure 4).

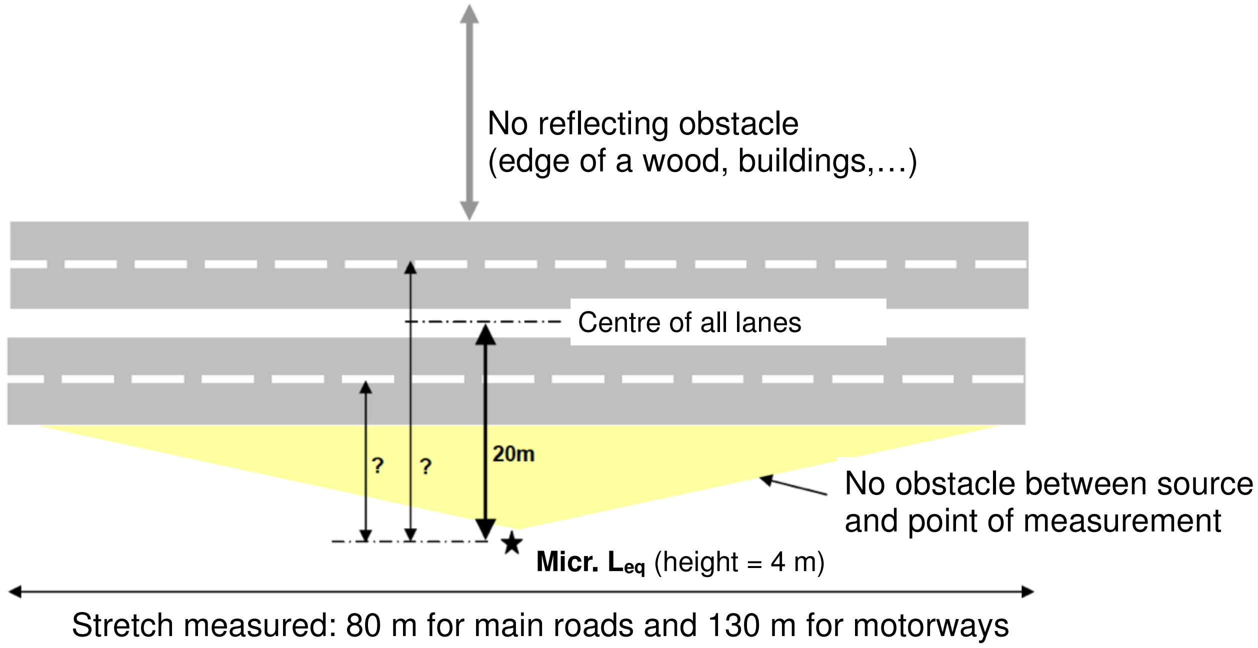


Figure 4: Roadside microphone position (SEM method).

The area around the microphone must be free from obstacles over a length of 80 m for main roads and 130 m for motorways. If a guardrail or any other obstacle is likely to influence the propagation of sound, the microphone shall be placed higher. In this case, the results shall be normalized to the usual conditions (20 m distance from the road centre and 4 m above the road surface). The following correction is therefore used:

$$A_d = 10 \cdot \log\left(\frac{r_2}{r_1}\right),$$

where r_i is the "real" distance, including distance and height.

5.3. <u>Duration and frequency of measurements</u>

In order to characterise noise emission from a source, measurements must be taken over a period of one week (ideally 2 weeks in order to avoid the effects of extraordinary events, for example, weather conditions). Measurements must also be repeated during the year in order to guarantee seasonal monitoring (4 measurements per year).

In the case of road noise monitoring, the output of data must take place every half-hour. Notably, during those 30 minutes intervals when traffic exceeds 1000 vehicles, the number of light vehicles and heavy vehicles per lane shall be recorded, as well as their respective average speeds (cf. Figure 5). During these intervals, measurements and counts shall be suspended in the event of any noise other than road traffic (planes, bells, agricultural machinery, etc.). This will permit the comparison of L_{Aeq} values with the values calculated on the basis of mathematical models, and thus possibly the application of correction factors to the results from models (cf. 5.3).

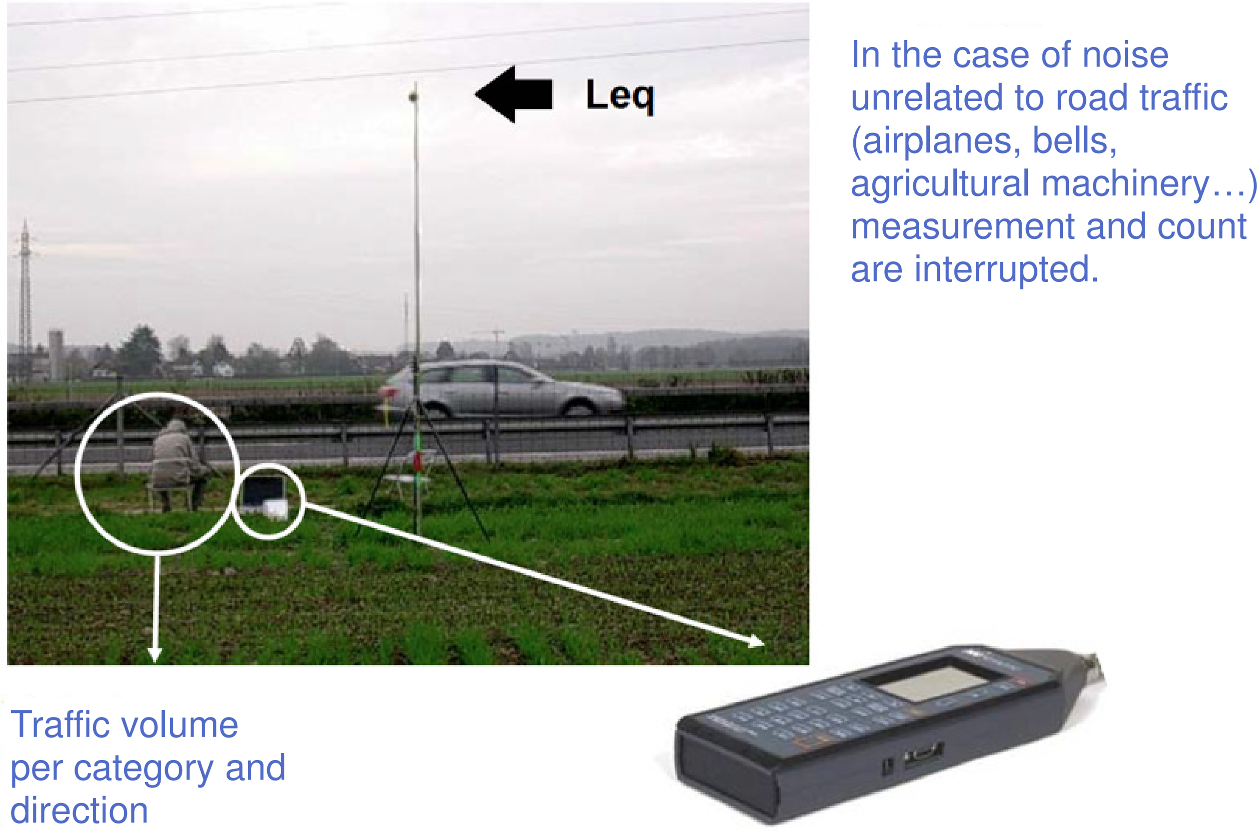


Figure 5: During brief time intervals (30 minutes) of "intensive" measuring, the presence of a technician is required in order to momentarily suspend measurements and counts when necessary.

5.4. Data collection

5.4.1. Data at the point of measurement

Firstly, it is necessary to acquire data on the characteristics of the infrastructure being monitored directly at the point of measurement. As indicated on the computer screen-shot in Figure 6, in the case of a road infrastructure, this will include primarily information on the location: i.e. traffic corridor, municipality, coordinates, side of the road and description of the location. Other information shall pertain to the road: type and category of road surface, year of paving, gradient and maximum speed permitted. These aspects have a direct influence on noise emission.

The above information shall be accompanied by maps and photographs at the point of measurement.

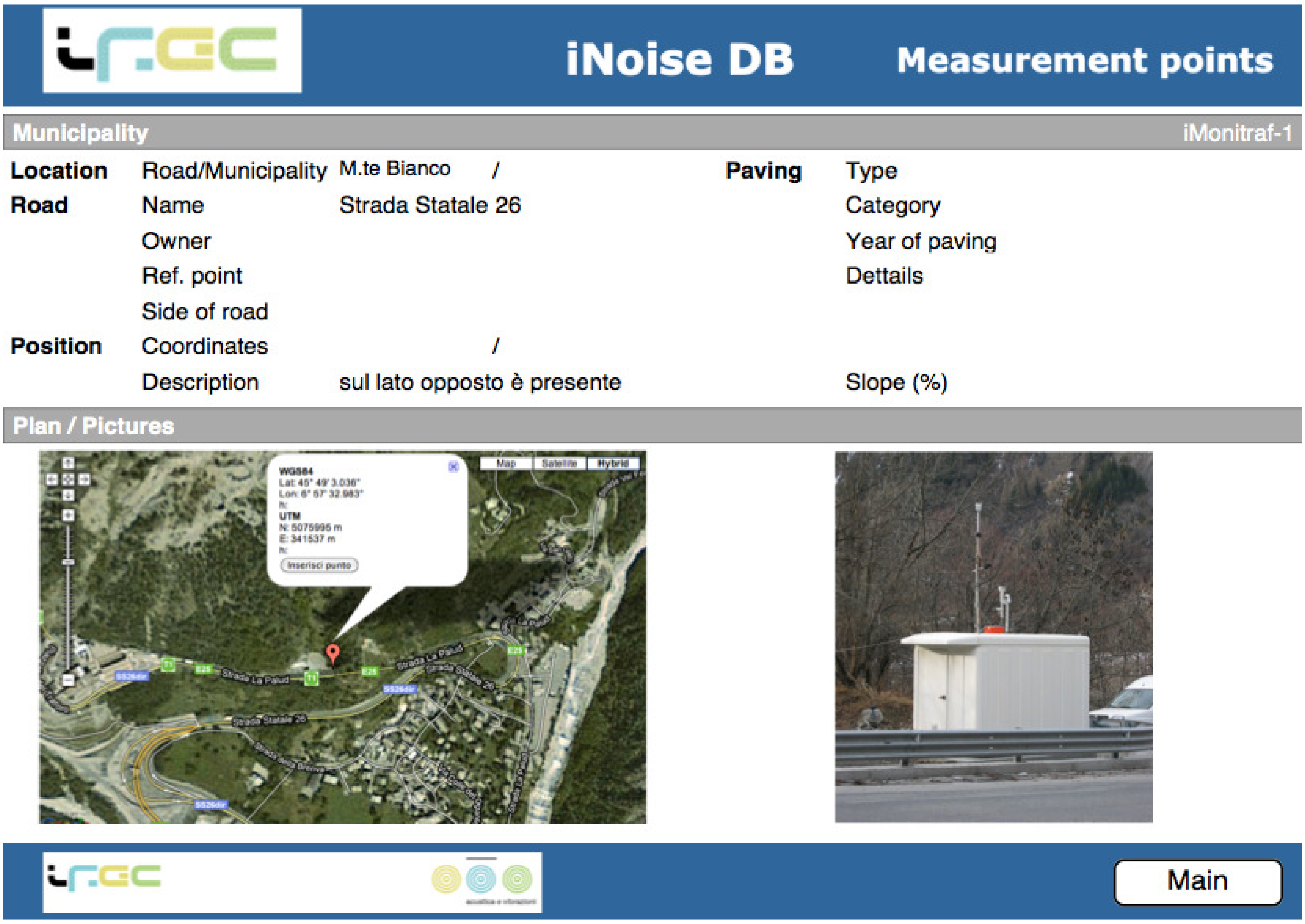


Figure 6: Data collection regarding the road infrastructure.

5.4.2. Data on measurements

For each measurement, the date and time (start and finish) must be recorded. The position of the microphone (i.e. distance from the middle of the road, and height above the road surface) must be recorded for each measurement. Figure 7 shows how the characterisation of weather conditions is considered on the basis of air and road surface temperatures. The latter is very important as it has a direct influence on noise emission and must be recorded, particularly during “intensive” measurement intervals.

Measurement								
Period	Date	11/11/2010	-	11/11/2010	**Mic. position**	from middle of road	20 m
	Time	10:00	-	10:50		H above the road	4 m
Temp.	Air (min-max)	2.5 °C	-	13.7 °C	**Speed**	max allowed	120 km/h
	Air (average)		3.7 °C			actual	120 km/h
	Asphalt (min-max)	3.8 °C	-	20.5 °C	**Instruments**	Noise measur.	Symphonie 01dB
	Asphalt (average)		4.7 °C				
Remarks:							

Figure 7: Data for a single measurement of road noise. It must be pointed out the importance of recording information on the measurement interval, the position of the microphone as well as weather conditions (for ex. air and road surface temperature).

Another important factor influencing noise emission is determined by precipitation.

The acquisition of the equivalent continuous A-weighted pressure level (L_{Aeq}) on a half-hourly basis is of primary importance for the accurate measurement of noise. Whenever the memory of the acquisition system allows, it is also important to gather some statistical values – the minimum value (L_{min}), the maximum value (L_{max},) and various percentiles (L_5, L_{10}, L_{50}, L_{90}, L_{95}, L_{99}) – as well as the third octave band sound spectrum.

5.4.3. Data on vehicle traffic

In order to make better use of noise data, it is necessary to consider traffic volumes recorded during the corresponding intervals. Ideally, the number of less noisy vehicles and that of very noisy vehicles on each lane on a semi-hourly basis should be determined. Pending more precise criteria from the WP6, this paper pragmatically differentiates only between light and heavy vehicles, even though the drawing line is not always obvious. With precise information on the traffic composition and average speeds, it is possible to calculate the noise level with the help of mathematical models as well as to compare the calculated and measured values. As an example, Figure 8 illustrates this procedure in detail on the basis of the STL-86+ model that is applied in Switzerland.

The difference between measured and calculated values allows the determination (for each location) of a correction factor K to apply to the models.

A similar procedure may be applied to the NMPB model that is used in Italy.

Specific sound levels for heavy vehicles (i.e. very noisy vehicles) and light vehicles (i.e. vehicles causing little noise) as a function of speed (v):

$$L_{eq,VL} = 43 + 10 \cdot \log\left(1 + \left(v/50\right)^3\right).$$

$$L_{eq,VP} = 43 + 10 \cdot \log\left[\left(1 + \left(v/50\right)^3\right) \cdot \left(1 + 20 \cdot \left(1 - v/150\right)\right)\right].$$

This provides the level of emission in the single lanes (i) over 1 hour (3600 s):

$$L_{eq,1h,i} = 10 \cdot \log\left(10^{\frac{L_{eq,VL}(120) + 10 \cdot \log(N1_i)}{10}} + 10^{\frac{L_{eq,VP}(120) + 10 \cdot \log(N2_i)}{10}}\right) + 10 \cdot \log\left(3600/\Delta t\right)$$

where $N1_i$ and $N2_i$ are, respectively, the number of vehicles emitting little noise and those emitting a lot of noise during the time interval Δt (in seconds) for the measurement in each lane.

To obtain the sound level at the microphone position (receiver), it is necessary to consider the attenuation of sound due to geometric divergence

$$A_{d,i} = 10 \cdot \log\left(1/d_i\right)$$

where d_i is the distance between the microphone and lane i, the attenuation of sound due to atmospheric absorption

$$A_{a,i} = -\alpha \cdot d_i$$

where α = 0.005 dB/m and the attenuation due to the ground

$$A_{g,i} = \frac{-20}{1 + h/2} \cdot \left(1 - e^{-d_i/300}\right)$$

where h is the height of the microphone above the road surface. Other types of attenuation for measurements on the roadside may be disregarded (provided measurements are carried out in accordance with the present guidelines).

For the sound level $L_{r,i}$ produced in one lane, the result is:

$$L_{r,i} = L_{eq,1h,i} + A_{d,i} + A_{a,i} + A_{g,i}$$

from which it is possible to calculate the total sound level with an energetic sum:

$$L_{r,tot} = 10 \cdot \log\left(\sum_i 10^{L_{r,i}/10}\right).$$

Figure 8: Computation of the sound level generated on the receiver by traffic on several lanes over 1 hour, based on algorithm STL-86+.

5.5. Calculating noise indicators

A "noise indicator" is a physical quantity describing an environmental noise related to a harmful event. The noise indicators for the different time periods (07:00-19:00: L_{day}, 19:00-23.00: $L_{evening}$, 23:00-07:00: L_{night}) may be calculated as an average based on half-hourly measurements effected over the various periods

$$L_{descr} = 10 \cdot \log\left(\sum_{i=1}^{n} 10^{L_{eq,i}/10}\right) - 10 \cdot \log(n) ,$$

where n is the number of data collected in the time interval under consideration.

$L_{eq,j}$ values may be determined using an algorithm to obtain yearly average values on the basis of half-hourly data on traffic per lane. The resulting values will be corrected with the K factor that was determined during “intensive” monitoring periods.

5.6. Characterising the road surface

Road noise is determined by the traffic flow of various vehicle categories and their specific emission factors which depend primarily on the interaction between the vehicle and the road surface (tires rolling on the asphalt) and on the presence of a combustion engine inside the vehicle.

For a better understanding of the causes of the evolution of sound levels in a transit corridor, it is not sufficient to only gather data on the evolution of traffic, but to also to rely on information on specific noise emissions, particularly those from the road surface which may increase over time due to deterioration or improve as a result of maintenance work.

For this reason, the guidelines recommend periodic measurements of the emissivity of the road surface. Two standardized methods may be used for this: the SPB (statistical pass-by method) and the CPX method (trolley method).

The **SPB method** is described in ISO 11819-1 (Acoustic-measurements of the influence of road surfaces on traffic noise - Part 1, Statistical Pass-By Method, 1997). This measurement must be taken near a traffic counter according to the methods illustrated schematically in Figure 9 which also shows the standard location of the microphone: i.e. 7.5 m distance from the middle of the lane being considered and 1.2 m above the road surface. The area around the microphone must be free of obstacles. If a guardrail or some other obstacle influences the propagation of sound, the microphone should be placed higher and the sound levels calculated for the standard geometry.

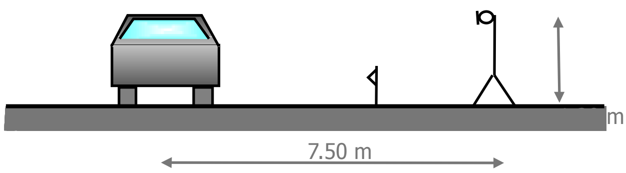


Figure 9: Schematic representation of the microphone position for measurements with the SPB method.

For a single vehicle, the signal measured by the microphone is A-weighted and averaged over time exponentially with a FAST time constant (125 ms). The averaged time history is acquired with a 0.1 s. frequency. The graph in Figure 10 shows an example of L_{Aeq} sound level trend when a vehicle passes by. The maximum level of sound pressure recorded during the passage is determined and used to characterise a vehicle on the basis of its noise emission level. Considering that a measure may be disrupted by other sources of environmental noise or by the passing of another vehicle, the validity of the maximum sound pressure level must be examined on the basis of 2 criteria:

- “no disturbance”: there may be no other noise source influencing $L_{Aeq,max}$;
- “10 dB leap”: the temporal series of data $L_{Aeq}(t)$ must decrease in a monotonic manner (with appropriate tolerance) by at least 10 dB(A) on either side of the maximum value.

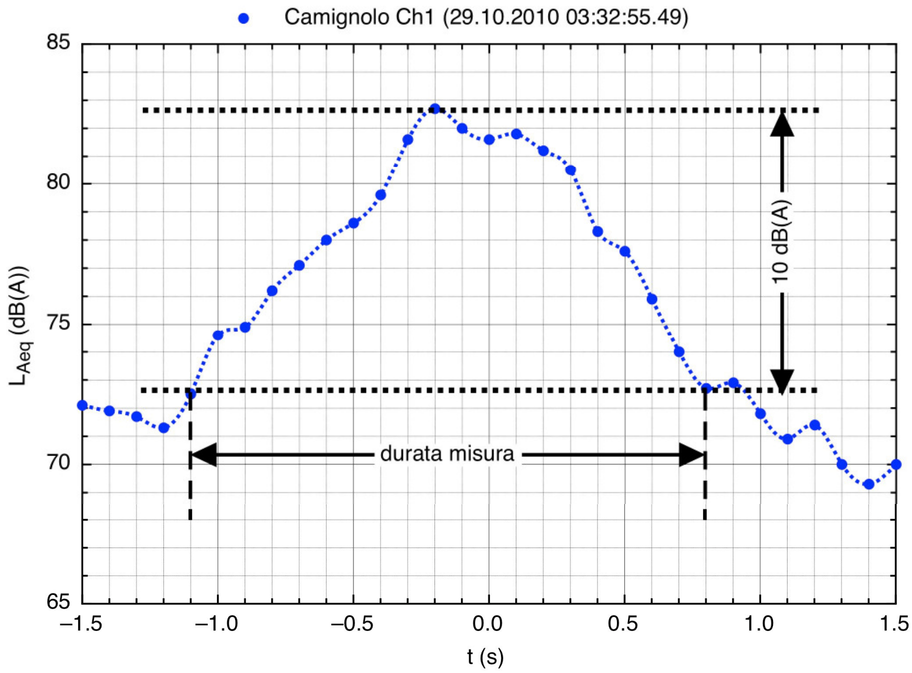


Figure 10: Pattern of the equivalent sound pressure level at a single vehicle pass-by [20]. These measurements were carried out in Camignolo (St. Gotthard traffic corridor, south-bound) on 29 October 2010 (03:32:55.49) and show the requirements in terms of signal to background noise ratio.

The SPB method is used to determine the effect of road paving *in one point* (in one section) in relation to the actual traffic fleet. The noise assessment is based on the statistical analysis of noise emissions normalised to the speeds of a large number of vehicles. This allows us to extract information on the various categories of vehicles.

The **CPX method** (continuous near-field measures) involves measuring the sound level with 2 microphones placed in a measurement trolley with sound insulation near the two wheels. The A-weighted sound level is measured continuously for each tire along the entire road section. The microphone signals are recorded with an 8 Hz frequency (i.e. every 125 ms). Measurements on the motorway are normally carried out at 80 km/h. The speed of the vehicle, the air temperature and the position (GPS) are all measured on a continuous basis.

Near-field measurements can determine the acoustic characteristics of the paving over an entire road section. These characteristics provide in particular:

- information on the homogeneity of acoustical performance of one type of paving;
- increased reproducibility and comparability (cf. for example, the evolution of the road cover over time) as the specificity of the location and undesired changes (reflections, traffic composition, driving style, tires…) have no influence on the results.

Compared to the SPB method, the CPX method

- ignores engine noise (it focuses only on rolling noise);
- allows for spot measurements that are extended over an entire road section.

For the subsequent calculation of noise immissions, CPX measures need to be calibrated with the SPB method. To this purpose, 20 to 30 spot measurements must be carried out using the SPB method.

5.7. Minimum specifications for measurement instruments

Microphones are sensitive to environmental conditions (wind, rain and snow). By choosing appropriate microphones for outdoor use, the diaphragms can be protected from environmental influences. Typically, an outdoor monitoring microphone will have an anti-bird screen, a wind shield and a rain cover, with all elements forming an integral part of the system's omnidirectional acoustic characteristics.

The minimum sound pressure that can be measured by a sound pressure meter is reached when the noise level emitted by its microphone coincides with the background noise of the preamplifier. This level – the lower limit of the dynamic range – must be 40 dB(A). The upper limit of the dynamic range[2] must be 110 dB(A).

The frequency responses (the amplitude of sound pressure on the diaphragm related to the electric signal generated by the microphone for different frequencies) must allow for measurements in a range of frequencies between 20 Hz and 10 kHz.

The memory capacity of the sound level meter must be sufficient to permit the recording of half-hourly sound equivalent values, the third octave band sound spectrum, the minimum and maximum values, and the percentile levels[3] L_5, L_{10}, L_{50}, L_{90}, L_{95}, L_{99} of the equivalent level. It should be noted that the statistical analysis is meaningful only if it is carried out with a FAST time constant (125 ms) which, according to a fair approximation, is the response time of the human ear.

Weather stations – possibly located near the sound level meter station – must allow for the acquisition of data every half-hour. In terms of road surface temperature, it is normally sufficient to carry out one measurement during "intensive" measurement periods. A thermographic technique may also be used.

The traffic counter must ensure measurement of half-hourly passages divided by carriageway and by vehicle category (cf. Table 10).

2 The maximum measurable sound pressure level depends on the elasticity of the diaphragm which causes distortion above a certain limit.

3 For example, L_{90} indicates the level which was exceeded 90% of the time.

	Vehicle category
1	Buses and coaches
2	Motorcycles
3	Cars
4	Cars with trailer / campers
5	Vans
6	Vans with trailer
7	Vans with semitrailer
8	Trucks
9	Semi-trailer trucks
10	Trailer trucks

Table 10 Categories of vehicles

During intensive measuring, the traffic counters must also be capable of surveying the traffic on each lane with the relative speeds.

5.8. Calibration procedures

Calibrations are needed in order to establish the relationship between sound pressure and the electrical signal from the microphone, and must be performed using a frequency of 1 kHz.

Calibrations must be carried out at regular intervals, at least at the beginning of each measurement campaign. The results of calibrations will rule out data in case of negative outcomes, and represent – along with the selection of the location and the measurement set-up – an important basis for collecting high quality rough data.

To guarantee a high degree of comparability of the data measured by various authorities along the main traffic corridors, periodic comparative campaigns (every 2 years) are recommended. On these occasions, ring calibrations will be carried out. The instruments used in the various regions will be brought to one location – ideally near an automatic traffic counter – where they will measure noise along a road at the same time and under identical conditions (i.e. distance and height of microphones).

Thanks to this type of comparative analysis of measurement systems, systematic errors can be identified and eliminated.

Measurements carried out using the CPX method should be undertaken with the same measurement system (same trolley, same acquisition system with the same set of parameters, etc.).

5.9. Validation of acquired sound level data

After acquisition, data must be validated. As these guidelines pertain to monitoring in direct proximity of the road, the validation procedure shall deal with three specific aspects described below.

5.9.1. Changes due to significant weather events

In the event of precipitation, rain or snow, or wind speed above 5 m/s, the data shall not be considered valid and shall not be utilised in further analyses. The presence of rain can be inferred directly from the data. In fact, as shown in Figure 11, the difference in noise level measured at 1 kHz and at 10 kHz is substantially reduced when the asphalt is wet. More precisely, if the difference is below 15 dB(A), it can be safely assumed that the asphalt was wet.

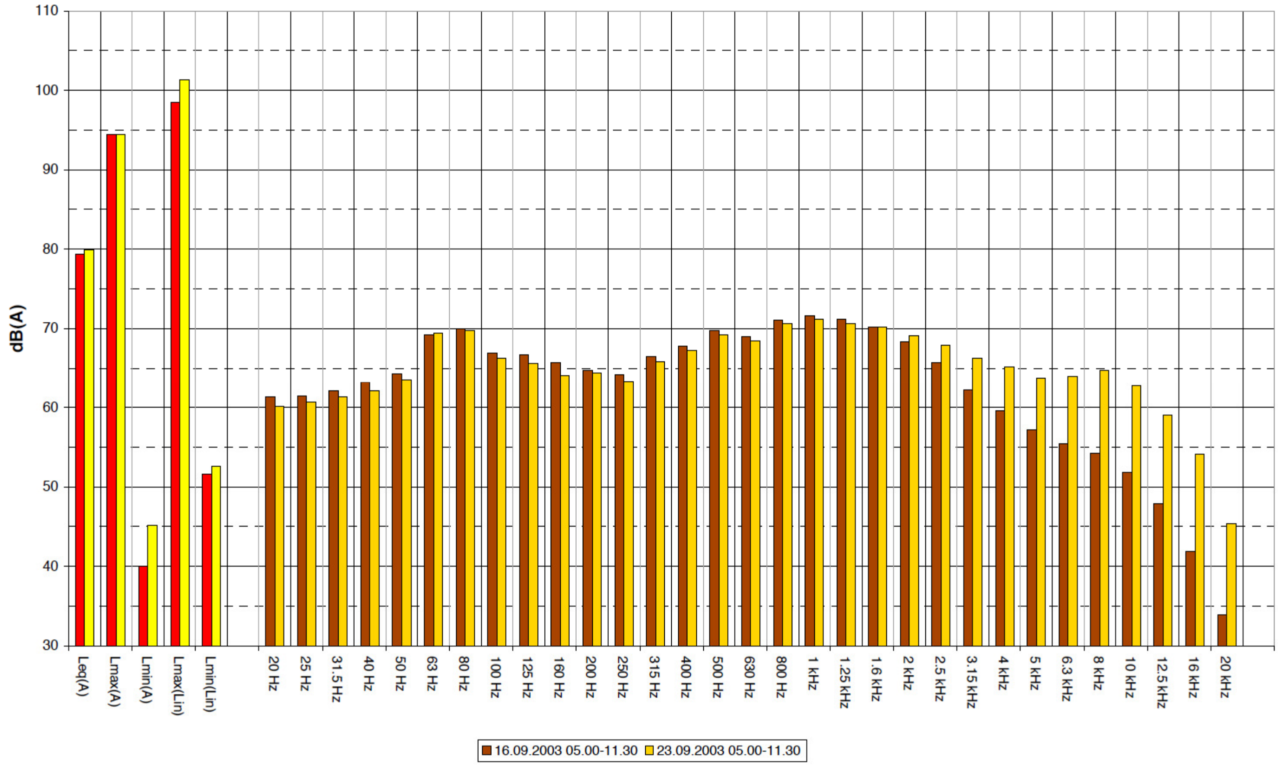


Figure 11: Comparison of noise levels and their spectrums during 2 working weekdays on dry asphalt (16.09.2003) and wet asphalt (23.09.2003), with almost identical traffic intensity [16]. The data was measured at the Moleno measuring station along the St. Gotthard transit corridor.

5.9.2. Significant changes due to traffic interruptions

Changes brought on by interruptions to traffic shall be managed through the assessment of traffic data, either measured or obtained from the managers of the infrastructure, in order to verify the actual contribution on the noise values in the long term.

5.9.3. Significant changes in the L_{Aeq} time profile

Significant changes in noise levels caused by events not attributable to vehicular traffic are identified by the single operators. To this end, series of historical data may be used to retrieve minimum and maximum statistical levels for data comparison.

The methodology elaborated within the framework of the “Osservatorio ambientale della Svizzera italiana” project (OASI, [21]) allows to determine typical daily-patterns based on historical data series. Figure 12 illustrates the results for Camignolo, on the south-bound carriageway. The typical patterns on work days (no. 3), on Saturdays (no. 6), on Sundays (no. 2) and on Friday evenings (no. 5) are clearly visible.

Similar patterns – which in case of limited or spot data sets are easier to obtain without a cluster algorithm, but rather by calculating a typical day to represent similar ones (working day in winter, working day in summer, bank holiday in winter, bank holiday in summer…) – may be used to easily identify significant alterations of sound levels in the time profile as a result of extraordinary events. This kind of data must be excluded from subsequent analyses.

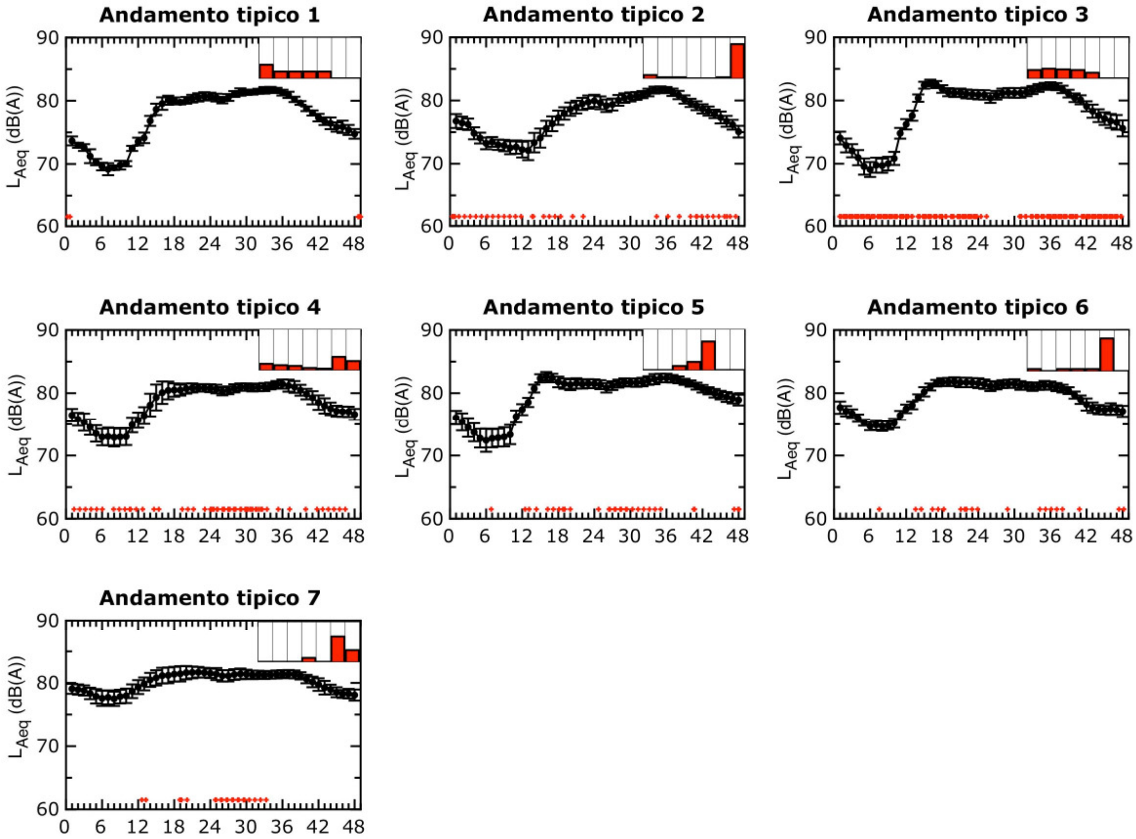


Figure 12: Typical sound level (L_{Aeq}) patterns obtained from historical series in Camignolo (St. Gotthard corridor) on the south-bound carriageway (2004). The small graph in the upper right corner shows the days of the week exhibiting the typical pattern (the first small column refers to Mondays, the second to Tuesdays and so forth). The small crosses below indicate the day of the year belonging to each cluster. The abscissa was divided into 365 units, with the days in January on the left and those in December on the right.

5.10. <u>Data management</u>

In order to gather data in a structured manner within a centralised information system, the results of measurements must be provided in a suitable format. Namely, they will have to be included in an Excel worksheet, one for each measurement point and with filenames having the following format: "**DATI_FONOMETRICI_Strade_**Nomevalico_**#.xls**"
(i.e. SOUND_LEVEL_DATA_Roads_AlpineCorssing_#.xls)
explicitly indicating the transit corridor (Alpine crossing), with "#" representing the progressive number of the measurement, for instance:

DATI_FONOMETRICI_Strade_Courmayeur SS26 Valle d'Aosta_1.xls.

GENERAL INFORMATION – SINGLE MEASURING POINT	
Main transit road	
Municipality	
Road name	
Owner of the infrastructure	
Reference point (km)	
Position of the station: x coordinate	
Position of the station: y coordinate	
Roadside (east or west)	
Description of the measuring point	
Number of lanes in each direction	
Maximum speed allowed	
Type of road surface (AC 6, AC 8, ..., AMR 4, ACMR 6, ... SMA 6, SMA 8, ..., MA, OB, ...)	
Category of road surface (self-draining asphalt, mastic asphalt, concrete)	
Year of paving	
Slope (%)	
Profile detail (sunken, raised, level)	
Distance (d) between the microphone and the road center (in meters)	
Height of the microphone above the infrastructure (in meters)	
Obstacles to sound propagation	
Noise measuring instrument	
Map / Picture	

Note:

(white)	writing field
(yellow)	data pasting field

Figure 13: Excel worksheet containing general information on an individual measurement point.

The Excel file comprises 4 worksheets.

The first worksheet "INFORMATION" (cf. Figure 13), is for general information about the individual measurement point. It presents the minimum requirements described in subsection 9 of the guidelines.

The second worksheet "BASIS_DATA", is used to enter the noise data described in subsection 10 of the guidelines and normalised to a 20 m distance from the middle of the road with the microphone at a height of 4 m, the traffic data count (number of vehicles and speed on each lane and for each category of vehicles) and the weather data (air temperature and asphalt temperature). In the last column of the table, “abnormal” data are indicated (with an “x”).

The lanes (C) are numbered progressively from west to east, i.e. if there are 4 lanes, lane 1 would be the normal south-bound lane, lane 2 the southbound overtaking lane, lane 3 the northbound overtaking lane and lane 4 the normal northbound lane.

On the 2 remaining Excel worksheets (cf. Chapter 6), measurement results will be summarised in tabular form ("SUMMARY_T") and in graphic form ("SUMMARY_G").

5.11. Summary of measurement modes

The main operational modes for measuring road noise are summarised in Table 11.

Type of measurement	Duration in days	Position	Conditions	Interval of data recording	Sampling requirements	Abnormal events
Noise data	7-14	h = 4 m, d = 20 m	Free field	30 min	Time constant FAST	Handled by technicians
Weather data	7-14	Near the sound level measurement station	-	30 min	Based on the characteristics of the weather stations	
Traffic data	7-14	Near the sound level measurement station	-	30 min	Based on the characteristics of the stations	

Table 11 Summary of road measurement modes and related data (weather, traffic).

6. Comment to the guidelines for the monitoring of railway noise

Similarly to the guidelines for road noise, the guidelines for monitoring railway noise are divided into 10 main chapters, each comprising several ciphers. The various chapters are commented on hereunder. For aspects which are common to both, please refer to the corresponding chapter of the guidelines for monitoring road noise (cf. Chapter 5).

6.1. Goal of the guidelines

In much the same way as for monitoring road noise, the guidelines for monitoring railway noise focus on the assessment of noise emissions. There are however substantial differences compared to road noise, and these differences influence the manner of characterising the emission. Road noise is characterised by a signal that is more continuous when compared to railway noise. The latter is composed of a series of events (cf. Figure 14, upper graph) in which the noise level may vary due to the different noises emitted by the various carriages of a train.

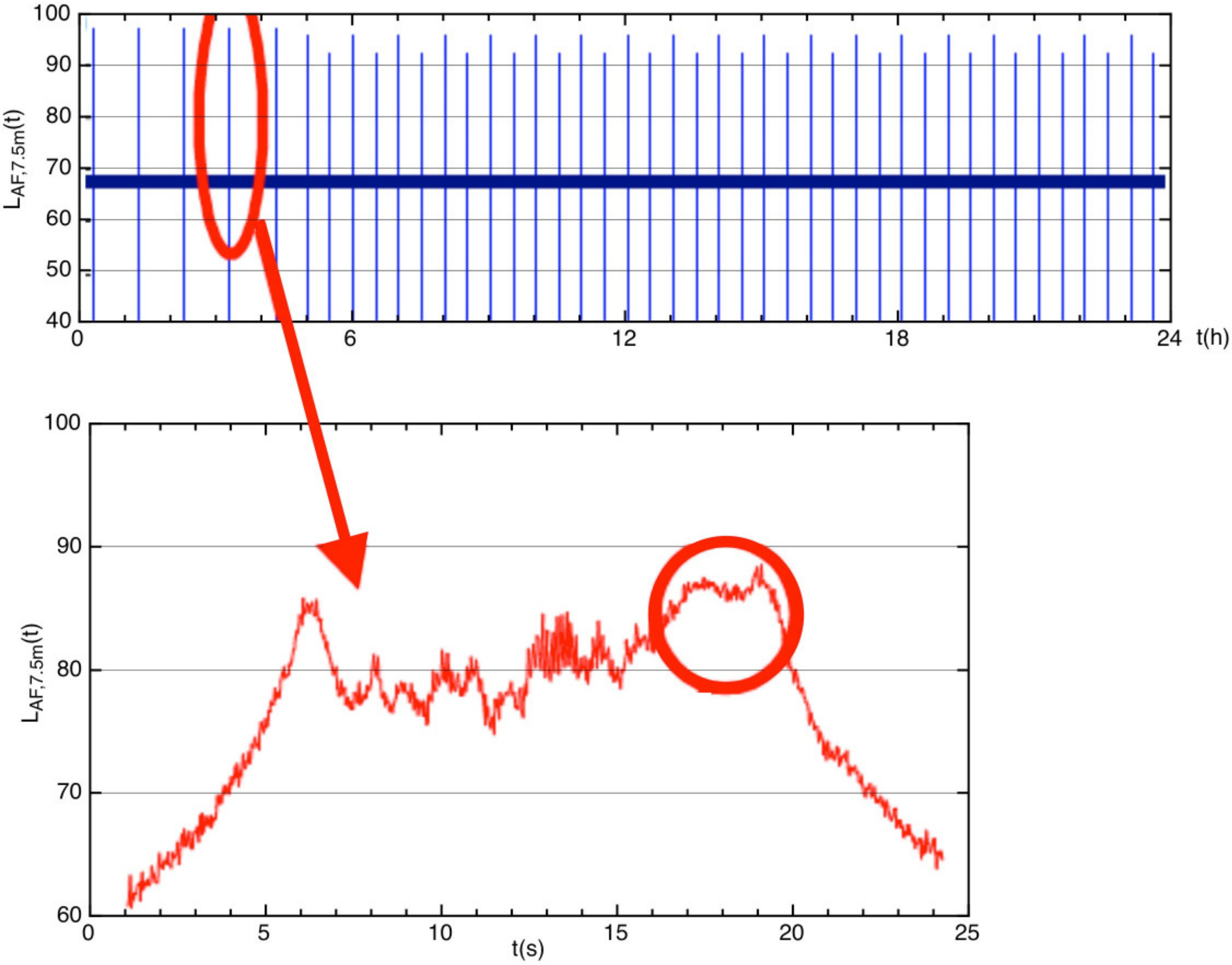


Figure 14: Examples of monitoring along a railway: the sound level L_{Aeq} calculated on all the train passages over 24 hours is approximately 67 dB(A) (cf. upper graph); the L_{Aeq} assessed for a single passage is approximately 80 dB(A).

The level of sound emission may be calculated considering a notional time-history of the noise during a train pass-by as illustrated in Figure 15 which also shows some of the recurrent notions in these guidelines. The maximum sound level $L_{AF,max}$ is the maximum A-weighted sound pressure level with a FAST time constant during one single passage.

The sound exposure level (SEL) is calculated by integrating the squared pressure over the whole pass-by and normalising to 1 sec

$$SEL = 10 \cdot \log\left(\frac{1}{1s} \int_{t_1}^{t_2} \frac{p^2(t)}{p_0^2} dt \right).$$

SEL is the resulting sound level if the overall energy were emitted in 1 sec.

The sound exposure during the pass-by of the train (Transit Exposure Level, TEL) is anchored in ISO 3095. It is obtained from the sound level measured at 7.5 m from the axis of the track and at a height of 1.2 m with the same integral as SEL (that is over the entire passage, including rising and falling parts), but normalised to the pass-by time of a train.

$$TEL = SEL - 10 \cdot \log\left(T_p\right).$$

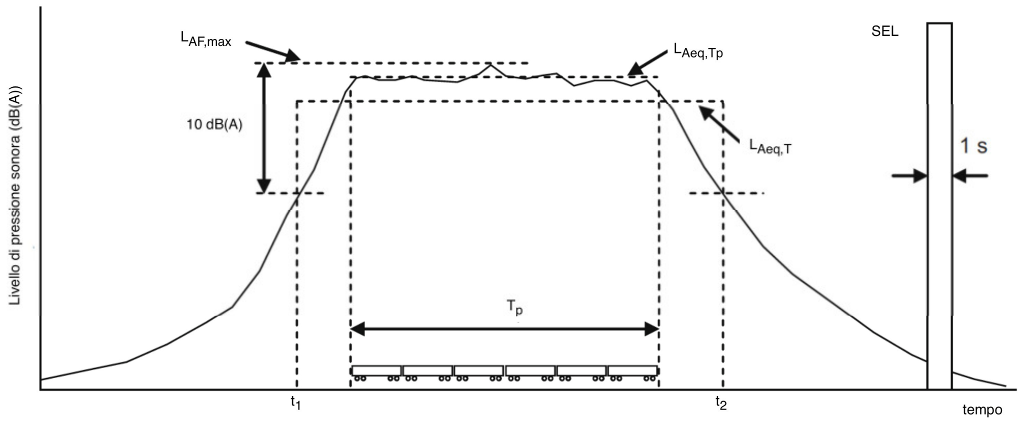


Figure 15: Notional time history of train pass-by noise indicating various quantities: the passage time $T_p = v/L$ (v = speed) and L = length of the train); the time interval (t_2-t_1) representing the duration of the event, i.e. the time during which $L_{AF} \geq L_{AF,max}$ – 10 dB(A) and may be calculated as follows: $t_2 - t_1 = T_p + 0.06 \cdot d$, where d is the distance from the observer.

The TEL value is highly dependent upon the speed of the train. In order to compare the emission values of several trains as well as the measurement points characterised by various pass-by speeds, it is necessary to normalise values to a unitary reference speed. Normally, this reference speed is set at 80 km/h and the respective TEL value is abbreviated as TEL 80. Since passenger trains travel at much higher speeds, TEL 120 (the TEL value for a speed of 120 km/h) is also used.

Various factors determine the dependence on speed. The following conversion formulas are used:

$$TEL\,80 = TEL - 30 \cdot \log(v/80)$$

$$TEL\,120 = TEL - 30 \cdot \log(v/120)$$

where v is the actual pass-by speed.

6.2. Location of monitoring points

As in the case of road noise, there are 2 fundamental criteria for establishing accurate measurements: the selection of the monitoring points along the infrastructure and the (geometrical) requirements in terms of microphone positioning.

6.2.1. Selecting a measurement point along the railway

One fundamental condition for obtaining high *quality rough data* is the *acoustical environment* in the area of measurement. The selected site must permit the free propagation of sound, particularly in the triangle-shaped area that lies between the track and the microphone and whose distance along the track is double the distance from the microphone on each side. The site should ensure the unhindered transmission of sound. To this end, the area must be free of sound absorbing materials (e.g. snow, tall vegetation) or reflecting materials (e.g. water, ice, asphalt, cement). Moreover, the area around the microphones, where the radius is equivalent to at least 3 times the measurement distance, must be free from large reflecting objects such as barriers, hills, rocks, bridges or buildings.

In order to guarantee a high quality of rough data, it is necessary to ensure that noise from other sources (e.g. other vehicles, industrial plants or wind) does not have a significant influence on the measurements. The maximum value $L_{Aeq,T=20s}$ of background noise relative to the microphone position must be at least 10 dB(A) below the L_{AFmax} values.

In order to obtain *valid, representative and reproducible* data, the measurement points must be chosen according to the following criteria:

- speed of passage,
- type of track,
- type of sleepers.

Moreover, to guarantee a high quality of rough data, the choice of measurement site must ensure that:

- the speed of the trains is constant, based on a fair approximation,
- the distance from structures such as bridges is more than 100 m;
- the distance from the signals (semaphores) is more than 1000 m;
- any curve in the tracks has a radius of at least 1'500 m;
- there are no switches on location;
- there are no joints (welded tracks), visible surface defects (burnt tracks, holes due to corrosion or bulges caused by the compression of external material between the wheel and the rail) in the measurement section; there should be no discernible impact noise due to welds or loose sleepers.

6.2.2. Location of the microphone on the side of the track

As stated by ISO 3095 [12], the microphone must be placed at a distance of 7.5 m from the centre of the track and at a height of 1.2 m above the upper level of the rail.

6.3. Duration and frequency of measurements

In order to characterise noise emissions from a specific source, measurements must be taken over a period of one week, but a minimum of 4-5 days in order to avoid the effects of extraordinary events, for example, weather conditions. Measurements must also be repeated during the year in order to guarantee seasonal monitoring (4 measurements per year).

6.4. Data collection

The first data to be acquired are those on the characteristics at the point of measurement of the infrastructure being monitored: traffic corridor, municipality, coordinates, side of measurement (east or west), site description. Other information pertain to the railway itself: type of tracks, type of sleepers, and speed along the measured section. All these have a direct influence on noise emissions (cf. Figure 17).

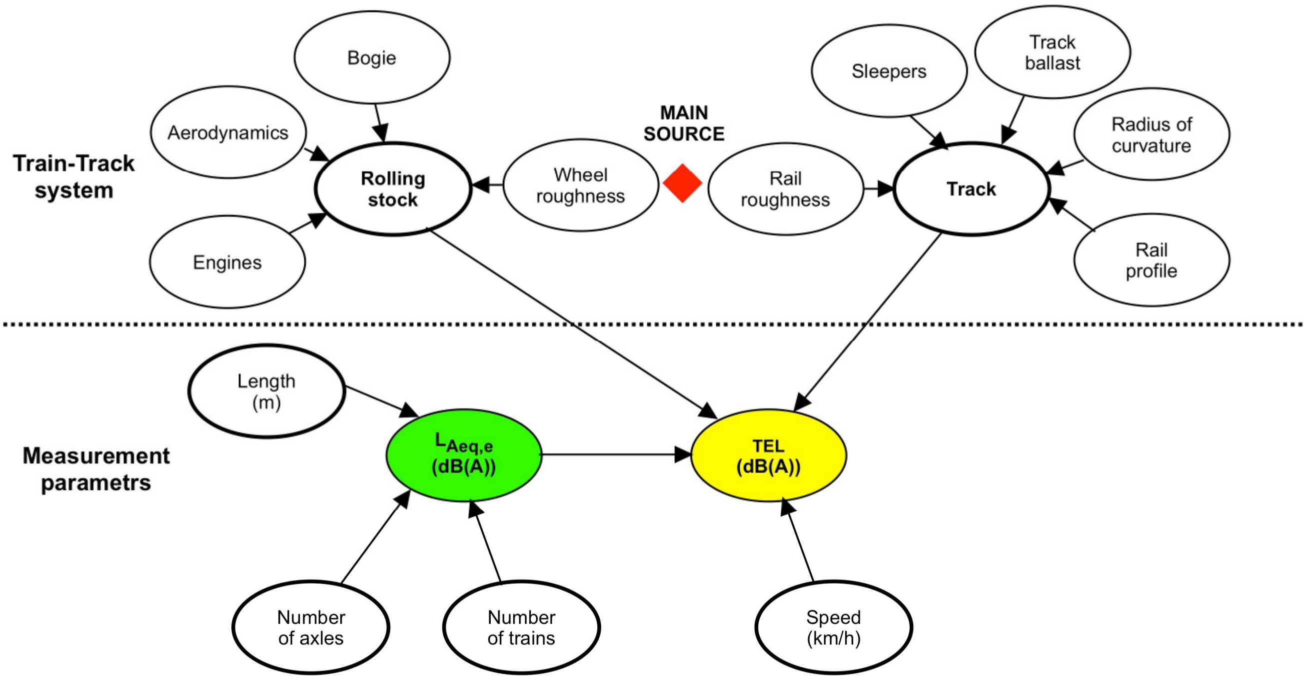


Figure 16: Train-track system and monitoring parameters [7].

One factor of considerable importance is the type of train. During the monitoring period, the frequencies according to train type must be measured while, at other times, it is sufficient to simply record information on average frequencies within the different time periods (day, evening and night).

In consideration of the fact that speed varies from one train to the other, it is advisable to measure speed directly, if possible. Once the speed is known, the length of the train may be calculated on the basis of its pass-by time T_p. Another important parameter is the number of axles as this factor is closely connected to noise emissions. All these parameters – including the type of train – may be determined through the use of axle-counters.

The conditions on a fully equipped measurement site are illustrated in Figure 17. The costs[4] of such a measurement station is approximately 120'000 CHF, half of which would be for the building along the tracks (with particular reference to safety issues).

A less expensive, yet also less complete, alternative for the identification of trains is to request the transit schedules from the managers of the railway section being monitored.

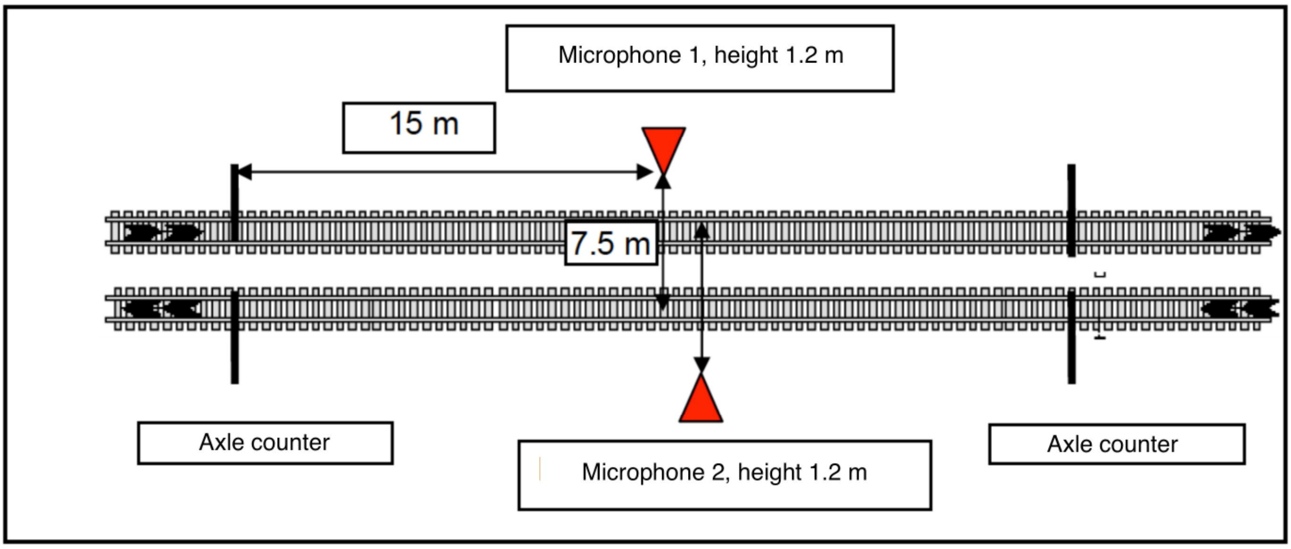


Figure 17: Railway noise measuring station with axle counters [7]

The measurement begins when a preset threshold is passed. The time constant FAST must be used in order to determine the time profile $L_{AF}(t)$ of the single transit events. On this basis, it is possible to determine the start and end times t_1 e t_2 (hh:mm:ss) respectively, the duration of the pass-by, the noise level L_{Aeq} and the sound exposure level (SEL), as well as to calculate the transit exposure level (TEL).

Weather stations – possibly located near the sound level measurement station – should inasmuch as possible allow the acquisition of data (air temperature and precipitation) during the pass-by (on a half-hourly basis). In addition, there should be no ice, frost or other products derived from freezing water on the rail.

6.5. Calculating noise indicators

The noise indicators L_{day}, $L_{evening}$, L_{night} and L_{den} may be calculated on the basis of the sound exposure levels of the single events (SEL_i) as described in Chapter 5 of the guidelines. Since these indicators are determined on the total passages, they can be used to describe the overall noise impact on a railroad. They also permit a comparison between two different railway corridors and a study of the evolution of noise pollution over time, distinguishing between the different time periods (day, evening and night).

4 Private communication with Matthias Brechbühl

6.6. Characterising the rails

As illustrated schematically in Figure 16, the pass-by noise emission of a train is largely determined as a result of the rolling noise produced by the interaction between wheel and rail as a function of speed. The rolling noise results from the combined **roughness** of the wheel and the rail, as well as the dynamic behaviour of the rail and the wheel-set. It is therefore recommended that a measurement of rail roughness near the point of measurement be taken. Roughness may be described with a single indicator $L_{\lambda CA}$ (in dB) [10] which considers the relevance of the various wavelengths in the roughness and is thus closely linked to noise emission. The determination of this indicator is an important requisite for comparing the measurements taken in different locations.

6.7. Minimum specifications for measurement instruments

With regard to sound level meters, the same requirements as indicated in detail for the monitoring of road noise above should apply. In particular, the dynamic range must be between 40 dB(A) and 110 dB(A) and the frequency responses must allow the measurement of a frequency range between 20 Hz and 10 kHz.

For the analysis of the noise generated by the pass-by of trains, the measurement uses a FAST time constant (125 ms).

Weather stations must allow for the acquisition of data on a half-hourly basis.

The axle counter – if used – must permit the measurement and recording of the parameters listed in Table 12. For a **single pass-by,** the following information is needed:

- train speed;
- pass-by duration;
- number of axles;
- train type.

These data must be completed with the data needed in order to describe **overall passages**:

- railway traffic in both directions over each period of time (day, evening and night);
- average speed;
- average duration of a pass-by.

Parameters	Indications on the parameter	Remarks
Date	(dd:mm:yyyy)	Date of pass-by
Time	(hh:mm:ss)	Time of pass-by
Speed	(km/h)	
Pass-by duration	(s)	
Length of the train	(m)	Calculated
Number of axles		
Type of train	Passenger train Freight train Service train Undefined	Determined on the basis of the number of axles for each wheel-set.

Table 12 Parameters measured with an axle counter.

6.8. Calibration procedures

Calibrations must be carried out in a manner similar to that specified in the case of road noise, at regular intervals (e.g. every 24 hours) and at least at the beginning of each measurement campaign. Calibration results will be used to discard data in the event of negative outcomes, and they represent – together with the selection of the measurement point and the set-up – an important basis for obtaining high-quality rough data.

In order to guarantee a high degree of data comparability as measured by various authorities involved in the railway corridors, it is recommended that periodic (every 2 year) comparative campaigns be organised during which ring calibrations may be carried out with *measurements being effected in parallel and calibrated with the same signal* (cf. 5.8).

6.9. Validation of acquired noise level data

Noise events which are not attributable to rail-traffic, or which are characterised by incidental phenomena, may be identified on the basis of the time of occurrence (coinciding with the passage of a train) and from the analysis of time profiles.

The L_{Aeq} values corresponding to train pas-by which were invalidated because of exceptional events must be substituted with the arithmetic mean value of L_{Aeq} calculated on all remaining passages. However, to ensure the validity of the L_{Aeq} value in the reference period (day, evening and night), the number of passages invalidated by noise phenomena must not exceed 10% of all transits.

Noise level measures influenced by noisy weather events such as storms, heavy rain and strong winds (wind speed above 5 m/s) must be excluded. Alternatively, their contribution to the noise should be assessed in order to obtain the correct noise from the source being investigated.

6.10. Data management

Noise measurements must be recorded in a suitable format, allowing data to be shared and compared between the various monitoring authorities. Data shall be included in a separate Excel worksheet, one for each measuring point and each pass-by.

The filename

"**DATI_FONOMETRICI_BASE_Ferrovie_**Nomevalico**_#.xls**"
(BASE_SOUND_LEVEL_DATA_Railway_Crossing_#.xls)

explicitly indicates the transit corridor (Alpine crossing). The "#" represents the progressive number of the measurement, for ex.: DATI_FONOMETRICI_BASE_Ferrovie_Frejus_1.xls.

The Excel file comprises 2 worksheets. The first worksheet "INFORMATION" (cf. Figure 18), is for general information about the individual measurement point. It presents the minimum requirements described in subsection 9 of the guidelines.

On the second worksheet "BASIS_DATA", the white cells are for information on the train's pass-by (date, time, type of train, speed, number of axles and length of train). The measured data (L_{AF} (dB(A)) must be transcribed into the yellow cells. An example is provided in Chapter 7.1.

GENERAL INFORMATION – SINGLE MEASURING POINT	
Main transit railway line	
Municipality	
Railway name	
Owner of the infrastructure	
Reference point (km)	
Position of the station: x coordinate	
Position of the station: y coordinate	
Side of tracks (east or west)	
Description of the measuring point	
Number of tracks	
Maximum speed allowed	
Sleepers (material)	
Trackbed	
Rail roughness LACA (dB)	
Slope (%)	
Profile detail (sunken, raised, level)	
Distance (d) between the microphone and the track center	
Height of the microphone above the infrastructure (in meters)	
Obstacles to sound propagation	
Noise measuring instrument	
Map / Picture	

Note:

(white)	writing field
(yellow)	data pasting field

Figure 18: Excel worksheet for general information on each single measurement point of railway noise.

For a summary of an overall measurement campaign, the calculated values (for T_p, SEL, TEL and TEL 80) must be included in the summary file

"**DATI_FONOMETRICI_SOMMARIO_Ferrovia_**Nomevalico**_#.xls**",
(SOUND_LEVEL_DATA_SUMMARY_Railway_Crossing_#.xls)

which must be separate for each measurement campaign. This file also comprises several worksheets. The first worksheet is for general information on the measurement point. The second, "RESULTS", will present the results of each single measure in the white cells as illustrated in Figure 19.

TO BE FILLED IN WITH DATA MEASURED WITH A NORMALISED **FAST** TIME CONSTANT, 7.5 M FROM THE MIDDLE OF THE TRACK AND AT A HEIGHT OF 1.2 M (MEASURED FROM THE UPPER LEVEL OF THE RAILS) IN FREE-FIELD CONDITIONS. ABNORMAL DATA MUST BE EXCLUDED.

N. Pass-by	Date (dd.mm.yyyy)	Time of pass-by (hh:mm:ss)	Type of train	Duration of pass-by Tp (s)	SEL (dB(A))	TEL (dB(A))	TEL 80 (dB(A))
1	16.10.2010	09:28:00	Passenger train	5.75	**81.2**	**62.1**	**65.9**
2	17.10.2010	07:00:00		7.00	**81.2**	**62.1**	**65.9**
3	18.10.2010	19:00:00		6.50	**81.2**	**62.1**	**65.9**
4	20.10.2010	23:00:00		7.50	**81.2**	**62.1**	**65.9**
5	21.10.2010	23:30:00		5.75	**81.2**	**62.1**	**65.9**
6							
7							
8							

Figure 19: Excel worksheet for the summarised results of each single passage.

The third worksheet, "SUMMARY", contains the calculation of the noise indicators L_{day}, $L_{evening}$, L_{night} and L_{den} which will be presented both in tabular and graphic form.

6.11. <u>Summary of measurement modes</u>

The main operational modes for the measurement of railway noise are summarised in Table 13.

Type of measurement	**Duration in days**	**Position**	**Conditions**	**Sampling requirements**	**Abnormal events**
Noise data	7-14	h = 7.5 m, d = 1.2 m	Free field	Time constant FAST	c/o technicians
Weather data	7-14	Near the sound level measuring station	-	Depending on the characteristics of the weather station	

Table 13 Summary of measurement modes for railway noise.

7. Application

7.1. Support instruments

Some examples of support instruments are illustrated hereunder.

The worksheet "BASIS_DATA" of the "DATI_FONOMETRICI_Strade_Nomevalico_#.xls" file has been filled with data measured in Camignolo (St. Gotthard corridor) during the first two weeks of September 2011. The noise data measured are those for south-bound traffic and were standardized at 10 m distance between the edge of the road and the microphone and a height of 4 m (measurements are carried out at 6.5 m distance and 3.2 m height).

Figure 20 shows the contents of the third worksheet ("SUMMARY_T") of the Excel file. The results of measurements are summarised with the noise indicators: L_{day}, $L_{evening}$, L_{night} and L_{den}. For the same periods the table also shows the numbers of light and heavy vehicles as well as their respective speeds.

Date	Day (07-19)					Evening (19-23)				
	Lday	Light vehicles	Heavy vehicles	Average speed light vehicles	Average speed heavy vehicles	Levening	Light vehicles	Heavy vehicles	Average speed light vehicles	Average speed heavy vehicles
(dd.mm.yyyy)	dB(A)	Number	Number	km/h	km/h	dB(A)	Number	Number	km/h	km/h
01.09.2011	81.3	41836	3938	114	94	78.7	7419	379	121	92
02.09.2011	81.1	45406	3529	116	97	79.8	9927	266	120	97
03.09.2011	81.0	50804	1533	116	97	78.6	8591	102	113	99
04.09.2011	80.4	36908	317	110	95	78.8	7516	44	120	105
05.09.2011	81.4	39506	3516	114	95	77.7	5711	439	121	93
06.09.2011	80.9	38508	4580	115	94	77.9	5992	393	121	91
07.09.2011	81.0	40341	4476	115	95	78.3	6559	398	121	93
08.09.2011	80.9	42266	4323	115	94	78.6	7642	419	120	95
09.09.2011	80.9	45873	3764	115	95	79.5	10445	286	120	100
10.09.2011	80.8	49232	1610	116	94	78.4	8438	91	120	96
11.09.2011	79.8	40415	296	120	106	78.0	8261	72	119	99
12.09.2011	80.7	39010	3814	116	97	77.2	5439	357	122	96
13.09.2011	80.8	37448	4339	116	96	77.8	5578	388	122	96
14.09.2011	81.1	39156	4539	115	94	77.9	5821	364	122	100

Date	Night (23-07)					Den				
	Lnight	Light vehicles	Heavy vehicles	Average speed light vehicles	Average speed heavy vehicles	Lden	Light vehicles	Heavy vehicles	Average speed light vehicles	Average speed heavy vehicles
(dd.mm.yyyy)	dB(A)	Number	Number	km/h	km/h	dB(A)	Number	Number	km/h	km/h
01.09.2011	74.6	5648	462	121	96	78.2	54903	4779	118	94
02.09.2011	75.5	7071	434	121	98	78.1	62404	4229	118	97
03.09.2011	77.0	8910	368	120	96	78.0	68305	2003	117	97
04.09.2011	75.0	6117	71	115	96	77.4	50541	432	113	97
05.09.2011	75.2	5852	524	115	95	78.4	51069	4479	116	95
06.09.2011	74.2	5097	518	120	97	77.9	49597	5491	118	94
07.09.2011	74.4	5406	464	122	99	78.0	52306	5338	119	96
08.09.2011	74.4	5564	515	121	99	77.9	55472	5257	118	96
09.09.2011	75.4	7155	478	121	96	77.9	63473	4528	118	96
10.09.2011	76.4	8534	381	121	97	77.7	66204	2082	119	95
11.09.2011	74.8	6557	79	121	100	76.8	55233	447	120	103
12.09.2011	74.5	5690	554	119	97	77.7	50139	4725	118	97
13.09.2011	73.8	4657	478	123	95	77.7	47683	5205	119	95
14.09.2011	74.2	4986	508	121	96	78.1	49963	5411	118	95

Figure 20: Excel worksheet "SUMMARY_T" with measured values summarised in tabular form..

These same data are represented graphically on the fourth worksheet ("SUMMARY_G").

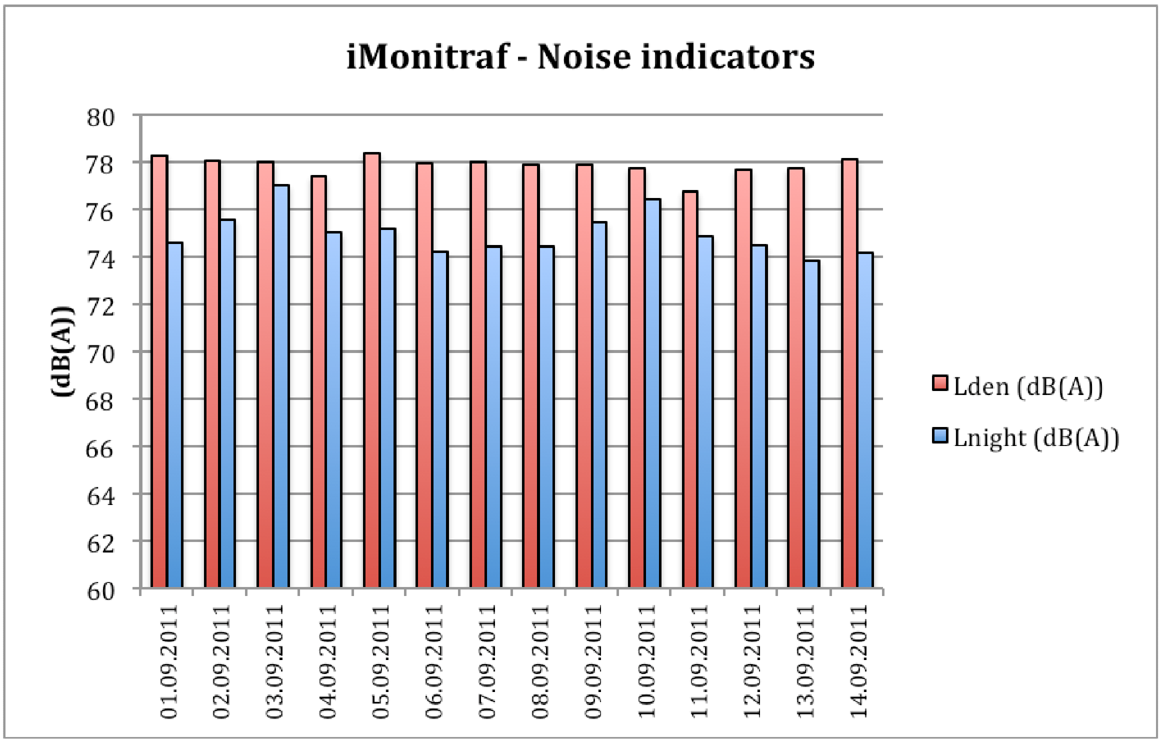


Figure 21: Graph extracted from Excel worksheet "SUMMARY_G" with noise indicators L_{den} and L_{night}. The maximum values of L_{night} refer to Saturdays.

Figure 21 illustrates an example of graph for noise indicators L_{den} and L_{night} measured in the first 2 weeks of September 2011 in Camignolo. Such graphics reveal interesting information on noise. For example, this graph shows L_{den} is almost the same except on Sundays (cf. September 4th and 11th 2011), when the lowest values were measured (approx. -1.5 dB(A)). During the night (L_{night}) there is more variation in measurements with higher values being measured on Saturdays (approx. +2.0 dB(A)). This phenomenon can be explained with increased traffic (+50%) caused by discos (cf. Figure 22).

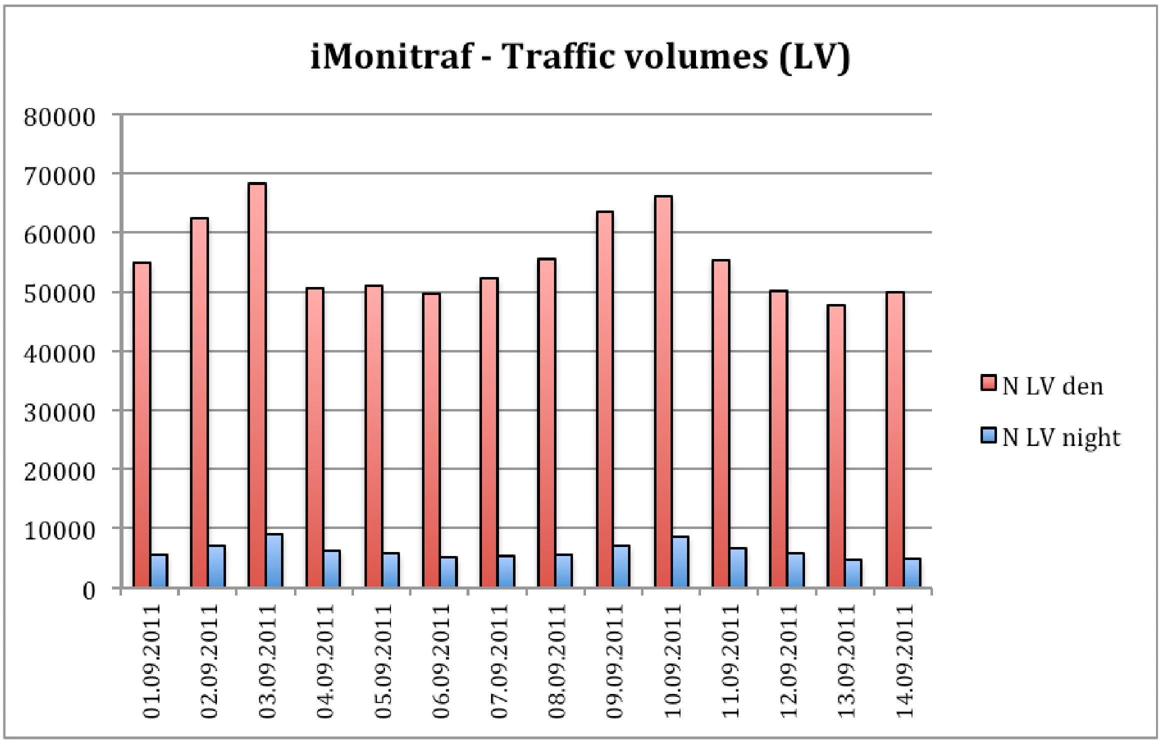


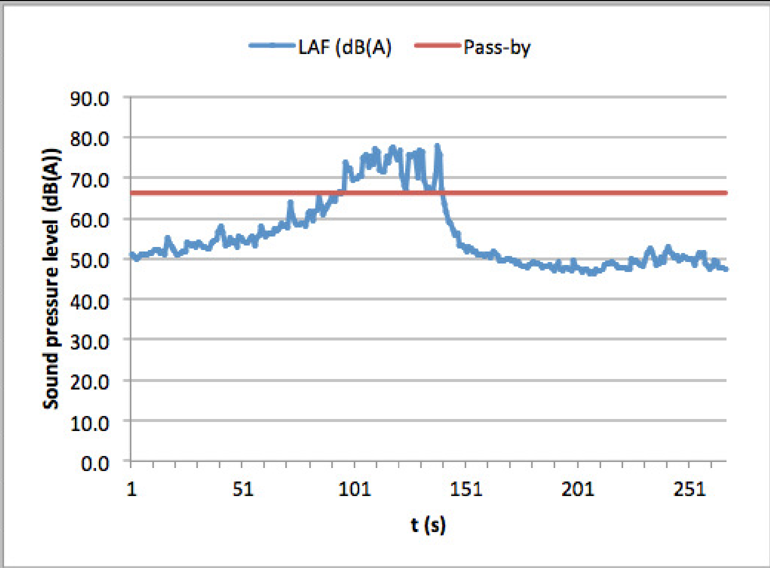
Figure 22: Graph extracted from Excel worksheet "SUMMARY_G" with daily traffic volumes (den) and nigh).

For the illustration of the file "DATI_FONOMETRICI_BASE_Ferrovia_Nomevalico_#.xls", the "BASIS_DATA" worksheet was filled in with the data measured in Caslano along the Ponte Tresa – Lugano road (16 October 2010, 09:28). As shown in Figure 23, based on the measured data (recorded in the yellow cells), the duration of the passage (T_p), the sound exposure level (SEL) and the transit exposure level (TEL e TEL 80) are automatically calculated.

The sound levels (L_{AF}) measured during the passage are also represented in a graph with a horizontal line above which are the pass-by data used for the calculation of exposure levels. The height of this line is obtained by subtracting 10 dB(A) from the maximum value of the moving average calculated on 5 (consecutive) values.

TO BE FILLED IN WITH DATA MEASURED WITH A NORMALISED **FAST** TIME CONSTANT, 7.5 M FROM THE MIDDLE OF THE TRACK AND AT A HEIGHT OF 1.2 M (MEASURED FROM THE UPPER LEVEL OF THE RAILS) IN FREE-FIELD CONDITIONS. ABNORMAL DATA MUST BE EXCLUDED.

Date (dd.mm.yyyy)	16.10.2010
Time pass-by (hh:mm:ss)	09:28:00
N. pass-by	1
Duration of pass-by Tp (s)	5.30
Speed (km/h)	60
Length (m)	88
Type of train	Passenger train
Lmin (dB(A))	46.2
Lmax (dB(A))	77.6
SEL (dB(A))	**81.2**
TEL (dB(A))	**74.0**
TEL 80 (dB(A))	**77.7**



0.125	51.1	50.68	0	66.2
0.250	50.8	50.64	0	66.2
0.375	50.1	50.68	0	66.2
0.500	50.4	50.64	0	66.2
0.625	51.0	50.72	0	66.2
0.750	50.9	50.94	0	66.2
0.875	51.2	51.14	0	66.2
1.000	51.2	51.24	0	66.2
1.125	51.4	51.52	0	66.2
1.250	51.5	51.72	0	66.2
1.375	52.3	51.92	0	66.2
1.500	52.2	51.9	0	66.2
1.625	52.2	51.98	0	66.2
1.750	51.3	51.72	0	66.2
1.875	51.9	52.28	0	66.2
2.000	51.0	52.6	0	66.2
2.125	55.0	52.88	0	66.2
2.250	53.8	52.94	0	66.2

Figure 23: Excel worksheet "BASIS_DATA" with values measured during an event summarised in tabular and graphic form.

7.2. Examples of application

This chapter describes the possibilities offered by undertaking a monitoring process based on these guidelines.

In Switzerland, railway noise has been monitored since 2003 in 6 stationary sites. The data obtained from these measuring stations, as well as those measured by a mobile station since 2009, have provided valuable knowledge on the characteristics and the evolution of railway noise. As an example, Figure 24 illustrates the distribution of TEL 80 frequencies for passenger trains measured in Steinen in 2003 and in 2010. This is a prime example of the evolution of rolling stock of passenger traffic: the percentage of noisy trains has been drastically reduced and trains with low emissions are more frequent. At the measuring site, this evolution is clearly evident as the rails have remained smooth over the entire period.

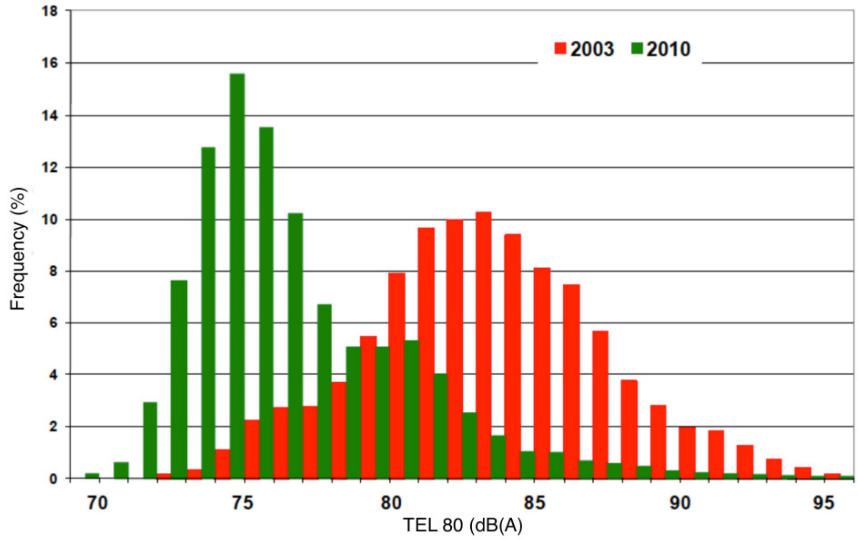


Figure 24: TEL 80 frequency distribution in Steinen for passenger trains in 2003 and 2010 [7].

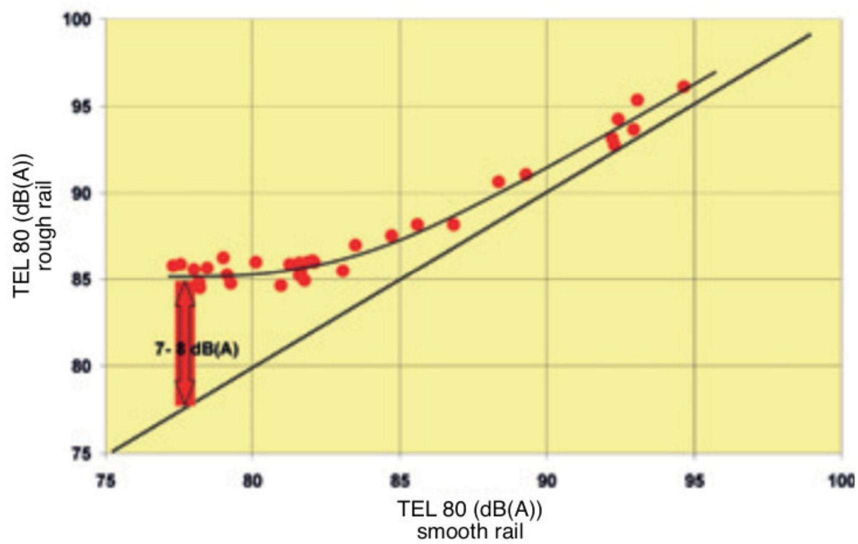


Figure 25: Transit exposure level normalised to 80 km/h for the same trains: the resulting value for a rough rail ($L_{\lambda,CA}$ = 8.7) is represented as a function of that measured for a smooth rail ($L_{\lambda,CA}$ = 2.3).

A further example shows the effect of rail roughness on noise [22]. This was studied by measuring the noise produced by trains near a track with rough rails ($L_{\lambda,CA}$ = 8.7) and the noise produced by the same trains a few hundred meters further in a section with smoothed rails ($L_{\lambda,CA}$ = 2.3). In Figure 25, the exposure levels during the passage of the train normalised at 80 km/h (TEL 80) measured near rough rails have been recorded as a function of those measured near smooth rails for the same trains. A close correlation is observed between the TEL 80 measured in 2 points in the case of noisy trains (high exposure levels): as the exposure level in the smooth rail section diminishes, so does that on the rough rail. This occurs only down to a certain threshold after which the curve flattens out. Below this threshold, the use of rolling stock that is less noisy will have no effect if the rail is in poor conditions.

Deterioration in road paving can also limit the potential noise reduction through other noise mitigating processes and can cause more noise emissions in equal conditions of traffic [20]. This was observed as a result of periodical measurements carried out with the SPB method (cf. Chapter 5.6). As can be seen in Figure 26, which shows the average noise levels L_{veh} of the single vehicles in Moleno (St. Gotthard corridor, south-bound carriageway), the average noise level of light vehicles is approximately 2 dB(A) below that in the opposite direction.

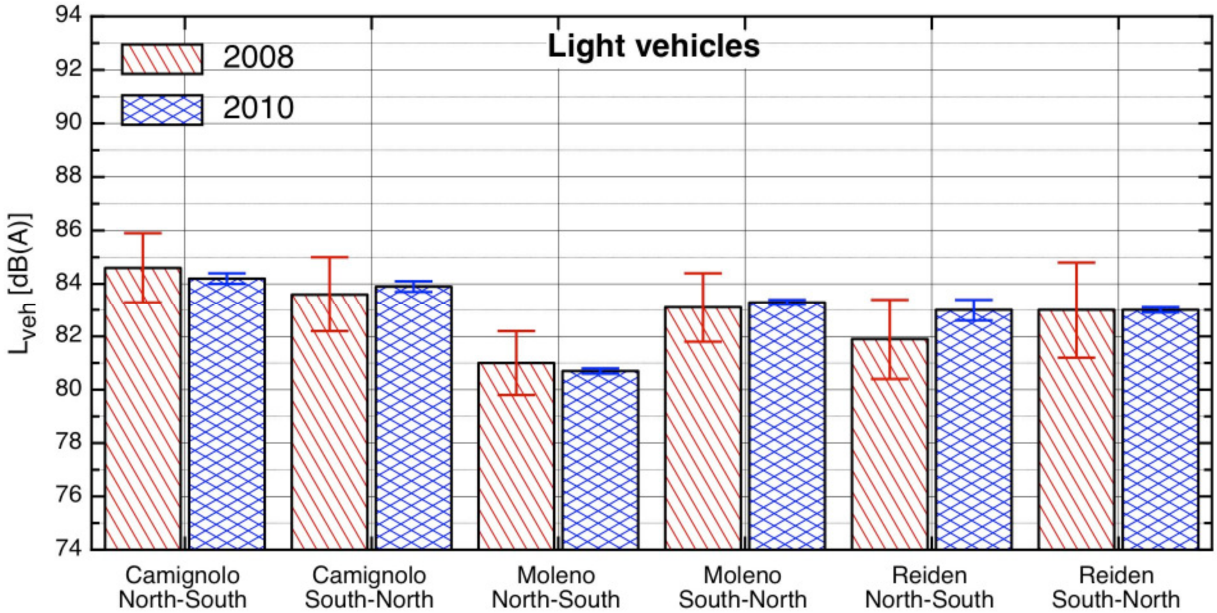


Figure 26: Evolution (2008-2010) of average noise levels (L_{veh}) of light vehicles measured at stationary monitoring points of the Swiss MfM-U project [20].

These examples illustrate the potential of coordinated monitoring along several traffic corridors for the road and the railway separately. It is however important to note that such monitoring provides an opportunity to observe the combined “road-railway” effect on noise pollution, which may be of great interest in the case of modal transfer, for example.