Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Acoustics I: noise abatement

Kurt Heutschi
2022-12-12

annoyance experiment with road traffic noise

experiment: procedure

- situation: daytime, relaxing on the balcony at home
- presentation of 6 samples of road traffic noise at different levels (90 seconds each)
- report the degree of annoyance on a scale of 0..10
  - 10: insupportable annoyance (unerträgliche Störung)
  - 8: strong annoyance (starke Störung)
  - 5: moderate annoyance (mässige Störung)
  - 3: weak annoyance (schwache Störung)
  - 0: no annoyance at all (keine Störung)

experiment: sounds

road traffic noise experiment: calibration for 65 dB(A)

- sample 1
- sample 2
- sample 3
- sample 4
- sample 5
- sample 6

experiment: evaluation

percentage of highly annoyed persons (reported annoyance 8, 9, 10):

Sample	number
1	
2	
3	
4	
5	
6	

experiment: evaluation

Leq's:

sample	Leq
1	65 dB(A)
2	50 dB(A)
3	70 dB(A)
4	55 dB(A)
5	60 dB(A)
6	45 dB(A)

experiment: evaluation

percentage of highly annoyed persons (reported annoyance 8, 9, 10):

results 2019:

sample	level	number
3	70 dB(A)	19
1	65 dB(A)	6
5	60 dB(A)	1
4	55 dB(A)	0
2	50 dB(A)	0
6	45 dB(A)	0

experiment: evaluation

percentage of highly annoyed persons (reported annoyance 8, 9, 10):

results 2014:

sample	level	number
3	70 dB(A)	14
1	65 dB(A)	7
5	60 dB(A)	2
4	55 dB(A)	0
2	50 dB(A)	0
6	45 dB(A)	0

experiment: evaluation

percentage of highly annoyed persons (reported annoyance 8, 9, 10):

results 2013:

sample	level	number
3	70 dB(A)	9
1	65 dB(A)	7
5	60 dB(A)	2
4	55 dB(A)	0
2	50 dB(A)	1
6	45 dB(A)	0

experiment: evaluation

percentage of highly annoyed persons (reported annoyance 8, 9, 10):

results 2012:

sample	level	number
3	70 dB(A)	16
1	65 dB(A)	10
5	60 dB(A)	4
4	55 dB(A)	0
2	50 dB(A)	0
6	45 dB(A)	0

experiment: evaluation

percentage of highly annoyed persons (reported annoyance 8, 9, 10):

results 2011:

sample	level	number
3	70 dB(A)	12
1	65 dB(A)	10
5	60 dB(A)	2
4	55 dB(A)	1
2	50 dB(A)	1
6	45 dB(A)	0

experiment: evaluation

percentage of highly annoyed persons (reported annoyance 8, 9, 10):

results 2010:

sample	level	number
3	70 dB(A)	11
1	65 dB(A)	5
5	60 dB(A)	2
4	55 dB(A)	1
2	50 dB(A)	0
6	45 dB(A)	0

experiment: evaluation

percentage of highly annoyed persons (reported annoyance 8, 9, 10):

results 2009:

sample	level	number
3	70 dB(A)	12
1	65 dB(A)	11
5	60 dB(A)	5
4	55 dB(A)	0
2	50 dB(A)	0
6	45 dB(A)	0

experiment: discussion of the experimental set-up?

experiment: discussion of the experimental set-up?

- visual impression is missing
- too short
- improper localization information
- listening room reflections that would not occur in the outdoor situation
- lack of other environmental noise sources
- samples with lower levels simulate larger distances to the source, however the temporal pattern is unaltered

introduction - what is noise?

introduction - what is noise?

- noise is sound, sound is not necessarily noise
- individual sensitivity relative to noise varies significantly
  - everyone has its individual rating scale
  - annoyance is strongly moderated by attitude towards noise source
  - depends on activity
  - depends on the momentary psychological situation
  - ...

introduction - what is noise?

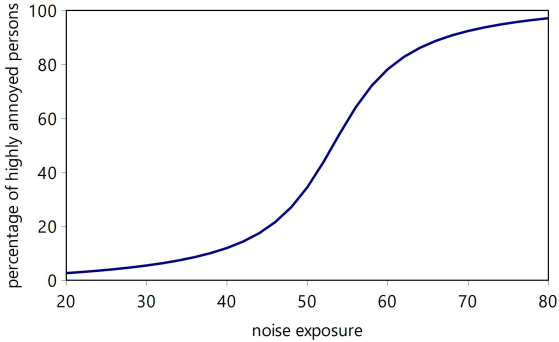
noise is unwanted sound

introduction - what is noise?

- noise can't be measured
- noise has to be assessed
- in practice: definition of objective assessment procedures for certain (well defined) noise sources (for an average person)
- method: questioning of people regarding their annoyance and comparison with noise exposure

introduction - what is noise?

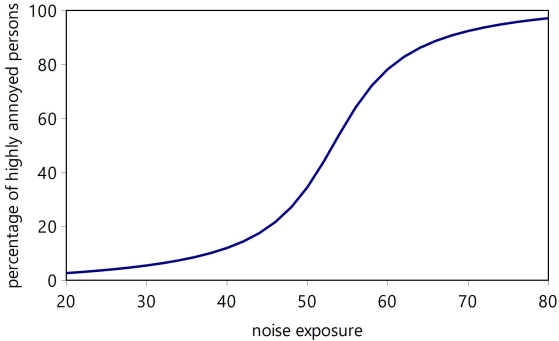
exposure - annoyance curves:



- very sensitive persons
- very noise resistant persons

introduction - what is noise?

exposure - annoyance curves:



- very sensitive persons
- very noise resistant persons

effects of noise

noise effects: person related

physiological effects: such as headache, cardio-vascular diseases, increased blood pressure, extensive pouring out of stress hormones, sleep disturbances and hearing defects in extreme cases

psychological effects: such as stress and nervousness, reduction of productivity

social effects: such as distortion of communication, social segregation (those who can afford, move to quieter areas)

noise effects: economical consequences

prices of real estates: noise exposition has substantial influence on the value of a real estate

noise abatement measures: costs for noise abatement measures such as installation of noise barriers, low noise pavements ...

health problems and loss of productivity: noise induced health problems cause health costs and loss of productivity

general aspects of today's assessment of noise

assessment of noise

- general assumption: noise annoyance = f(exposure)
  - exposure = f(intensity, number of events / duration noisy periods)
- exposure is described by average values
  - reference time period = 1 year
- assessment process: comparison of noise exposure with limiting values

assessment of noise

- sensitivity to noise = f(time of day)
- strategies to account for *time of day* dependency:
  - different limiting values = f(time of day)
    - L_d: level during day
    - L_n: level during night
  - one integral level with penalties = f(time of day)
    - L_{den}: *day-evening-night* level
    - L_{dn}: *day-night* level

assessment of noise: L_{den}

$$L_{den} = 10 \log \left(\frac{1}{24} \left[12 \cdot 10^{0.1(L_d)} + 4 \cdot 10^{0.1(L_e+5)} + 8 \cdot 10^{0.1(L_n+10)} \right] \right)$$

where
L_d: average receiver level during day period (12 h)
L_e: average receiver level during evening period (4 h)
L_n:average receiver level during night period (8 h)

assessment of noise: L_{dn}

$$L_{dn} = 10 \log \left(\frac{1}{24} \left[15 \cdot 10^{0.1(L_d)} + 9 \cdot 10^{0.1(L_n+10)} \right] \right)$$

where
L_d: average receiver level during day period (7:00 till 22:00)
L_n:average receiver level during night period (22:00 till 7:00)

influence of the source type

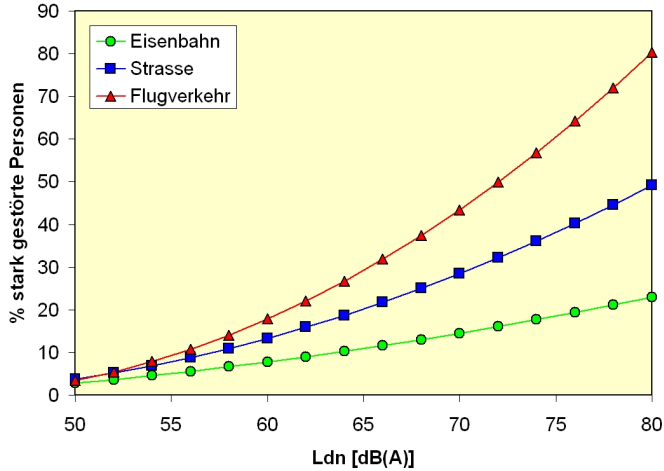
influence of the source type

- annoyance differs for different noise sources (for identical A-weighted sound pressure levels)
  - spectral content
  - temporal pattern
  - attitude towards the noise polluter

- $\rightarrow$ consequence: assessment is performed separately for each noise source type

influence of the source type

meta study of Miedema and Vos:



definition of limiting values

definition of limiting values

- data basis: response of annoyed people and corresponding exposure values
- evaluation of the category "highly annoyed" (8..10 on the 11 point scale from 0 to 10)
- derivation of a functional relation between exposure and percentage of highly annoyed persons
- limiting value: value of the exposure for 15...25 % highly annoyed persons

legal basis in Switzerland

legal basis in Switzerland

- Environment Protection Law USG
- Noise Abatement Ordinance LSV

legal basis in Switzerland: USG

- 1985: implementation of the Environment Protection Law USG
- goal: protection of humans, animals and plants against harmful and annoying impacts
- key concepts:
  - principle of precaution: detection of potential impacts in advance
  - limitation of the emission at the source
  - assessment by comparison of the exposure with impact thresholds
    - separate definition for most important source types
    - impact threshold guarantees that the population is not unreasonably annoyed
    - law is further detailed in the Noise Abatement Ordinance LSV

legal basis in Switzerland: USG

- 1985: implementation of the Environment Protection Law USG
- goal: protection of humans, animals and plants against harmful and annoying impacts
- key concepts:
  - principle of precaution: detection of potential impacts in advance
  - limitation of the emission at the source
  - assessment by comparison of the exposure with impact thresholds
    - separate definition for most important source types
    - impact threshold guarantees that the population is not unreasonably annoyed
    - law is further detailed in the Noise Abatement Ordinance LSV

legal basis in Switzerland: USG

- 1985: implementation of the Environment Protection Law USG
- goal: protection of humans, animals and plants against harmful and annoying impacts
- key concepts:
  - principle of precaution: detection of potential impacts in advance
  - limitation of the emission at the source
  - assessment by comparison of the exposure with impact thresholds
    - separate definition for most important source types
    - impact threshold guarantees that the population is not sincerely annoyed
    - law is further detailed in the Noise Abatement Ordinance LSV

legal basis in Switzerland: USG

- 1985: implementation of the Environment Protection Law USG
- goal: protection of humans, animals and plants against harmful and annoying impacts
- key concepts:
  - principle of precaution: detection of potential impacts in advance
  - limitation of the emission at the source
  - assessment by comparison of the exposure with impact thresholds
    - separate definition for most important source types
    - impact threshold guarantees that the population is not sincerely annoyed
    - law is further detailed in the Noise Abatement Ordinance LSV

legal basis in Switzerland: USG

- 1985: implementation of the Environment Protection Law USG
- goal: protection of humans, animals and plants against harmful and annoying impacts
- key concepts:
  - principle of precaution: detection of potential impacts in advance
  - limitation of the emission at the source
  - assessment by comparison of the exposure with impact thresholds
    - separate definition for most important source types
    - impact threshold guarantees that the population is not sincerely annoyed
    - law is further detailed in the Noise Abatement Ordinance LSV

legal basis in Switzerland: USG

- 1985: implementation of the Environment Protection Law USG
- goal: protection of humans, animals and plants against harmful and annoying impacts
- key concepts:
  - principle of precaution: detection of potential impacts in advance
  - limitation of the emission at the source
  - assessment by comparison of the exposure with impact thresholds
    - separate definition for most important source types
    - impact threshold guarantees that the population is not sincerely annoyed
    - law is further detailed in the Noise Abatement Ordinance LSV

legal basis in Switzerland: USG

- 1985: implementation of the Environment Protection Law USG
- goal: protection of humans, animals and plants against harmful and annoying impacts
- key concepts:
  - principle of precaution: detection of potential impacts in advance
  - limitation of the emission at the source
  - assessment by comparison of the exposure with impact thresholds
    - separate definition for most important source types
    - impact threshold guarantees that the population is not sincerely annoyed
    - law is further detailed in the Noise Abatement Ordinance LSV

legal basis in Switzerland: USG

- 1985: implementation of the Environment Protection Law USG
- goal: protection of humans, animals and plants against harmful and annoying impacts
- key concepts:
  - principle of precaution: detection of potential impacts in advance
  - limitation of the emission at the source
  - assessment by comparison of the exposure with impact thresholds
    - separate definition for most important source types
    - impact threshold guarantees that the population is not sincerely annoyed
    - law is further detailed in the Noise Abatement Ordinance LSV

Noise Abatement Ordinance LSV

- LSV has been put into force in 1987 (several extensions since then)
- aim: definition of specific rules and procedures for the application of the Environment Protection Law with respect to noise
- contains declarations:
  - for construction, operation and rehabilitation of facilities
  - for construction of new buildings with noise sensitive usage

LSV principles

scheme of limiting values

scheme of limiting values

- 3 types of limiting values:
  - impact threshold (IGW): limit of noise exposure that has to be tolerated
  - planning value (PW): implementation of the principle of precaution
  - alarm value (AW): identification of severe situations with urgent need for the realization of noise abatement measures
- 4 sensitivity levels (differentiation according to usage):
  - ESI: special zones for recreation
  - ESII: zones for living
  - ESIII: zones for living and industry (often centers of cities and villages)
  - ESIV: zones for industry only

scheme of limiting values

- 3 types of limiting values:
  - impact threshold (IGW): limit of noise exposure that has to be tolerated
  - planning value (PW): implementation of the principle of precaution
  - alarm value (AW): identification of severe situations with urgent need for the realization of noise abatement measures
- 4 sensitivity levels (differentiation according to usage):
  - ESI: special zones for recreation
  - ESII: zones for living
  - ESIII: zones for living and industry (often centers of cities and villages)
  - ESIV: zones for industry only

construction, operation and sanitation of facilities

$\longrightarrow$ noise sources

construction, operation and sanitation of facilities

- fundamental principle of the LSV: all noise sources have to reduce their emissions as much as possible at least to a degree that is affordable

construction, operation and sanitation of facilities

- requirements for new or heavily altered installations:
  - planning values in the neighborhood have to be satisfied
  - possible relaxations for private installations:
    - up to impact threshold (in case of public interest or disproportional effort, e.g. wind turbines)
  - possible relaxations for public installations:
    - no limitation (however above impact threshold installation of sound-proof windows is mandatory)

construction, operation and sanitation of facilities

- requirements for existing installations:
  - impact thresholds in the neighborhood have to be satisfied (if necessary, improvement of the installation)
  - possible relaxations for private installations:
    - up to alarm value (in case of disproportional effort)
  - possible relaxations for public installations:
    - no limitation (however above alarm value installation of sound-proof windows is mandatory)

construction permits

$\rightarrow$ receivers

construction permits

- LSV aims to prevent that new buildings with noise sensitive usage are built in areas with high noise burden

construction permits

- condition for new zones for buildings: in accordance with planning values
- condition for buildings in already developed zones: in accordance with impact thresholds
  - exceptions in case of public interest, e.g. if a gap in row of houses is closed to create a quiet backyard
- location for assessment: center of an open window of a room with noise sensitive usage
  - noise abatement strategies:
    - reduction of emission at the source
    - shielding of direct sound
    - orientation away from the source

assessment of road traffic noise

LSV: road traffic noise

- rating level Lr for day(6-22) / night(22-6)
  - $Lr = Leq + K1$
  - Leq: yearly average A-weighted sound pressure level
  - $K1 \leq 0$: level correction for low traffic densities

LSV: road traffic noise

scheme of limiting values (d=day, n=night):
PW: planning values
IGW: impact thresholds
AW: alarm values
ES: sensitivity level

ES	PWd	PWn	IGWd	IGWn	AWd	AWn
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

assessment of railway noise

LSV: railway noise

- rating level Lr for day(6-22) / night(22-6)
  - $Lr = Leq + K1$
  - Leq: yearly average A-weighted sound pressure level
  - $K1$: level correction as a function of train density:
    - -15 dB for less than 8 trains per day or night
    - -15...-5 for 8...80 trains per day or night
    - -5 dB for more than 80 trains per day or night
- scheme of limiting values identical to road traffic noise $\rightarrow$ 5 dB bonus for railway noise

assessment of industry noise

LSV: industry noise

- rating level Lr for day(7-19) / night(19-7)
  - large variation of the noise character $\rightarrow$ separation in *phases i*
  - $Lr = 10 \log \left(\sum 10^{(0.1 Lr_i)} \right)$
  - $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log \left(\frac{t_i}{t_o} \right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

- $Lr_i = Leq_i + K1_i + K2_i + K3_i + 10 \log\left(\frac{t_i}{t_o}\right)$
- Leq_i: equivalent A-weighted sound pressure level during phase i
- $K1_i$: source type dependent correction for phase i (5 or 10 dB)
- $K2_i$: tone correction for phase i (0, 2, 4 or 6 dB)
- $K3_i$: impulse correction for phase i (0, 2, 4 or 6 dB)
- t_i: average daily duration of phase i in minutes, where $t_i = \frac{T_i}{B}$
- T_i: yearly duration of phase i in minutes
- B: number of days per year the plant is in service
- $t_o = 720$ minutes
- scheme of limiting values identical to road traffic noise $\rightarrow$ at least 5 dB malus

LSV: industry noise

examples of tone and impulse correction:

Sample	tone	impulse
1: squeaking	4 or 6	0 or2
2: water jet	0 or 2	0
3: junk iron processing	0	2 or 4
4: unloading of a truck	2	0 or 2
5: bottles	0 or 2	4 or 6
6: motor saw	6	0
7: corona noise	4 or 6	0

assessment of noise from shooting ranges

LSV: noise from shooting ranges

- rating level Lr
  - $Lr = L + K$
  - L: average maximum level (A-Fast) of a single shot
  - $K = 10 \log(Dw + 3 \cdot Ds) + 3 \log(M) - 44$
    - Dw: number of half-days with activity during the week per year
    - Ds: number of half-days with activity on Sundays per year
    - M: number of shots fired in one year

LSV: noise from shooting ranges

scheme of limiting values:
PW: planning values
IGW: impact thresholds
AW: alarm values
ES: sensitivity level

ES	PW	IGW	AW
I	50	55	65
II	55	60	75
III	60	65	75
IV	65	70	80

assessment of aircraft noise

LSV: aircraft noise

- rating level Lr for
  - day period (6-22)
  - first hour of the night (22-23)
  - second hour of the night (23-24)
  - last hour of the night (5-6)
  - $Lr_{day} = 10 \log(10^{0.1 Lr_k} + 10^{0.1 Lr_g})$
    - Lr_k: small aviation
    - Lr_g: A-weighted, yearly average sound pressure level (6-22) from large aviation
  - Lr_{else}: A-weighted, yearly average sound pressure level from large aviation for the corresponding hour

LSV: aircraft noise

scheme of limiting values:

- limiting values during day similar to values for road traffic noise
- impact thresholds for the second and last night hour identical to night time values for road traffic noise
  - however "evaluation per hour" is stricter $\rightarrow$ no smearing over whole night

preview Acoustics 2

topics of Acoustics 2

- Electro-mechanical-acoustical analogies
- Microphones
- Loudspeakers
- Sound storage media
- Recording technique
- Auralisation
- Loudspeaker demonstration

lecturers of Acoustics 2

eth-acoustics-1