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EVALUATION OF NOISE LEVELS PRODUCED BY OPERATION AND MAINTENANCE ACTIVITIES OF A CONTINUOUS MOVEMENT FUNICULAR

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Continuous movement funicular is an innovative system for passenger transportation. This ropeway system is particularly suitable as a means of transportation for small and medium sized cities, for connections from public car parks to universities or commercial centers, or between centrally-located train or metro stations and peripheral suburbs. The advantages of this system are high availability, fully automatic operation and high carrying capacity. Disadvantages are high production costs and space requirements. Another disadvantage is also given by the closeness of such transport system with residential buildings, offices, hospitals or nursing home that could produce noise nuisance in sensitive noise receptors. In this paper an original method to evaluate the noise levels produced by funicular operation and maintenance activities is proposed.

1. Introduction

In the present paper a method is proposed to predict noise levels produced on sensitive receptors by maintenance and control activities of a surface urban transport system.

The noise level produced by maintenance and control activities has been evaluated considering the levels measured during a specific measurement campaign, with reference to frequency, recurrence of each activity and probability of an event occurring simultaneously with the others.

All possible combinations of activities which could occur during the same reference time period have been identified and the probability has been evaluated for the corresponding level to occur considering the frequency of recurrence of each activities.

Examined receptors for noise level inspection are located close to the ropeway because those are the receptors more exposed to the noise produced by operational and maintenance activities. However, such evaluations can be generalized and extended to all other receptors.

2. Measurement method

Noise measurement have the purpose to characterize acoustic emissions from maintenance and control activities and to evaluate the contribution of each activity to the equivalent noise level. Thus, for each activity a specific measure has been performed whose duration is representative of the whole acoustic phenomenon.

A-weighted equivalent continuous sound level (L_{eqA}) has been performed at night reference time (22:00- 6:00) because all maintenance and control activities are concentrated in that time period.

Phonometers used for measurement are of class 1 as defined by standard IEC60651, IEC 60804, IEC 61672 equipped with free-field microphones. The measurement chain respects the requirements of standards CEI 29-10. Instruments and/or measurement chain before and after each measure cycle have been controlled with a calibrator of class l, according to standard IEC 942:1988.

The measurement point has been selected in order to avoid other (external) sources which could affect the specific measure. Therefore the measurement distance has been suitably set up to 10 meters.

Table 1 shows A-weighted equivalent continuous sound levels for each maintenance and control activity measured in the time period representative of the event without any other disturbing sources.

Table 1: noise levels for each maintenance and control activities measured in the representative time period at a 10 m distance from source and without other disturbing sources

Activities	L_{eqA} [dB(A)]
Maintenance cart movement	64,5
Replacement of roller	62,3
Greasing and inspection of synchronization groups	46,7
Station wheel inspection	52,2
Station wheel replacement	52,5
Station belt replacement	72,8
Closing and opening cycles of platform-level doors	50,8
Preparatory control of ropeway start-up	59,3
System inspection at runtime	62,1
Generator start-up without power supply of the ring	71,6
Generator start-up with power supply of the ring	52,0
Verification of setting of maximum torque protection and maximum winch velocity protection	55,9
Verification of braking efficiency at station entry	61,7
Verification of retrieval winch drive	52,0
Test of winch braking system	-

3. Analysis method

Table 2 shows maintenance and control activities selected for the verification of noise level at sensitive receptors and the corresponding occurrence frequency. The combination of such activities and the probability that each one can occur during the night time period have both been identified under the following hypotheses:

- Preparatory control of ropeway and plant start-up have always been evaluated together;
- maximum number of night time activities is 6;
- inspection of synchronization groups and of station wheels are performed simultaneously for all the elements of the same station;
- each activity frequency has been considered equal to the expected one in the maintenance booklet and in the control service schedule;
- the frequency of different combined activities is obtained as composed probability of combination.

Under such hypotheses 110 different combinations of activities have been identified, each one characterized by a specific probability to occur during the night time reference period.

Table 2: list of maintenance and control disturbing activities

Code	Activity	Frequency
A	Maintenance cart movement	Monthly
B	Replacement of roller	1/2 years
C	Greasing and inspection of synchronization groups	1/3 months
D	Station wheel inspection	1/3 months
E	Station wheel replacement	1/2 years
F	Station belt replacement	1/2 years
G	Closing and opening cycles of platform-level doors	Daily
H	Preparatory control of ropeway start-up	Daily
I	System inspection at runtime	Daily
L	Generator start-up with power supply of the ring	Monthly
M	Verification of setting of maximum torque protection and maximum winch velocity protection	Monthly
N	Verification of braking efficiency at station entry	Monthly
O	Verification of retrieval winch drive	Monthly

The noise level produced by each event has been obtained by the resulting measurements. The noise level produced by the combination of more activities has been calculated according to the following relation:

$$L_{Aeq,i} = 10 \cdot \log \left[\frac{1}{T_r} \cdot \left(\sum_{j=1}^{n} \left(n_j \cdot T_j \cdot 10^{\frac{L_j}{10}} \right) + \left(\left(T_r - \sum_{j=1}^{n} n_j \cdot T_j \right) \cdot 10^{\frac{L_f}{10}} \right) \right) \right] \tag{1}$$

where L_j is the noise level produced by the jth activity, T_j is the duration of the jth activity, n_j is the frequency of the jth activity, T_r is the night time reference period, L_f is the background noise level in the night time reference period. Level L_j has been calculated according to the relation:

$$L_j = L_{j,10} - 10 \cdot \log \left(d_j / d_0 \right) \tag{2}$$

where $L_{j,10}$ is the noise level produced by the jth activity measured at 10 m distance, d_j is the distance of receptor from event, d_0 = 10 m.

4. Results

Evaluation of disturb produced by maintenance and control activities during the night time reference period has been performed at the first floor level which are closest to the ropeway. For each receptor, the noise level produced by each of the 110 combinations of activities has been calculated with the Eq. (1), subsequently, according to the probability of each combination, the statistical distribution of all possible noise levels has been evaluated. Table 3 shows the 110 combinations with the corresponding probability and the night time noise level. Charts in figures 1, 2, 3, 4 and 5 show statistical distribution of levels as foreseen for 4 receptors (R1, R2, R3 and R4), which are the most exposed to the noise emissions of the line.

Table 3: combinations of maintenance and control activities with corresponding probability and noise level

Combination of activities	Probability (%)	Noise level (dBA)			
		R1	R2	R3	R4
A	0,533333	51,45	50,84	50,29	49,85
B	0,022222	47,45	47,21	47,02	46,87
C	0,177778	46,00	46,00	46,00	46,00
D	0,177778	46,00	46,18	46,68	46,00
E	0,022222	46,00	46,01	46,03	46,00
F	0,022222	48,43	50,27	51,35	49,32
G	0,000000	46,00	46,00	46,02	46,00
H	0,000000	48,34	47,97	47,66	47,42
I	0,000000	47,68	47,41	47,19	47,02
L	0,533333	46,50	46,35	46,23	46,14
M	0,533333	46,37	46,29	46,23	46,18
N	0,533333	47,00	46,82	46,69	46,58
O	0,533333	46,45	46,31	46,20	46,12
A + B	0,000119	51,92	51,27	50,70	50,23
G + H + I	96,000000	49,40	48,92	48,52	48,18
A + G + H + I	0,380000	52,72	52,02	51,41	50,88
A + L	0,002844	51,60	50,95	50,38	49,91
A + M	0,002844	51,56	50,93	50,38	49,93
A + N	0,002844	51,76	51,12	50,56	50,10
A + O	0,002844	51,59	50,94	50,37	49,90
B + G + H + I	0,021333	50,12	49,58	49,12	48,73
B + L	0,000119	47,82	47,48	47,20	46,99
B + M	0,000119	47,72	47,43	47,20	47,02
B + N	0,000119	48,19	47,85	47,57	47,36
B + O	0,000119	47,78	47,45	47,18	46,97
C + G + H + I	0,170667	49,40	48,92	48,52	48,18
C + L	0,000948	46,50	46,35	46,23	46,14
C + M	0,000948	46,37	46,29	46,23	46,18
C + N	0,000948	47,00	46,82	46,69	46,58
C + O	0,000948	46,45	46,31	46,20	46,12
D + G + H + I	0,170667	49,40	49,01	48,91	48,18
D + L	0,000948	46,50	46,52	46,88	46,14
D + M	0,000948	46,37	46,46	46,87	46,18
D + N	0,000948	47,00	46,97	47,27	46,58
D + O	0,000948	46,45	46,48	46,85	46,12
E + G + H + I	0,021333	49,40	48,92	48,53	48,18
E + L	0,000119	46,50	46,36	46,26	46,14
E + M	0,000119	46,37	46,30	46,26	46,18
E + N	0,000119	47,00	46,83	46,71	46,58
E + O	0,000119	46,45	46,32	46,23	46,12
F + G + H + I	0,021333	50,68	51,60	52,25	50,47
F + L	0,000119	48,73	50,40	51,42	49,39
F + M	0,000119	48,64	50,38	51,42	49,41
F + N	0,000119	49,03	50,60	51,56	49,60
F + O	0,000119	48,69	50,39	51,41	49,38
A + B + G + H + I	0,000114	53,07	52,36	51,72	51,19
A + B + L	0,000001	52,05	51,38	50,78	50,28
A + B + M	0,000001	52,01	51,36	50,78	50,30
A + B + N	0,000001	52,20	51,53	50,94	50,46
A + B + O	0,000001	52,04	51,37	50,77	50,28
A + G + H + I + L	0,002027	52,83	52,11	51,47	50,93
A + G + H + I + M	0,002027	52,80	52,10	51,47	50,95
A + G + H + I + N	0,002027	52,95	52,24	51,61	51,08
A + G + H + I + O	0,002027	52,82	52,10	51,46	50,92

B + G + H + I + L	0,000114	50,32	49,73	49,23	48,80
B + G + H + I + M	0,000114	50,27	49,71	49,23	48,83
B + G + H + I + N	0,000114	50,53	49,96	49,46	49,05
B + G + H + I + O	0,000114	50,30	49,72	49,22	48,80
C + G + H + I + L	0,000910	49,64	49,10	48,65	48,26
C + G + H + I + M	0,000910	49,57	49,07	48,65	48,29
C + G + H + I + N	0,000910	49,88	49,36	48,91	48,54
C + G + H + I + O	0,000910	49,61	49,08	48,63	48,25
D + G + H + I + L	0,000910	49,64	49,19	49,03	48,26
D + G + H + I + M	0,000910	49,57	49,15	49,03	48,29
D + G + H + I + N	0,000910	49,88	49,44	49,28	48,54
D + G + H + I + O	0,000910	49,61	49,17	49,02	48,25
E + G + H + I + L	0,000114	49,64	49,10	48,66	48,26
E + G + H + I + M	0,000114	49,57	49,07	48,66	48,29
E + G + H + I + N	0,000114	49,88	49,36	48,93	48,54
E + G + H + I + O	0,000114	49,61	49,08	48,65	48,25
F + G + H + I + L	0,000114	50,86	51,70	52,30	50,52
F + G + H + I + M	0,000114	50,81	51,68	52,30	50,54
F + G + H + I + N	0,000114	51,04	51,84	52,42	50,69
F + G + H + I + O	0,000114	50,84	51,69	52,30	50,52
A + G + H + I + L + M	0,000011	52,91	52,18	51,54	50,99
A + G + H + I + L + N	0,000011	53,06	52,33	51,68	51,13
A + G + H + I + L + O	0,000011	52,93	52,19	51,53	50,97
A + G + H + I + M + N	0,000011	53,03	52,31	51,68	51,14
A + G + H + I + M + O	0,000011	52,90	52,17	51,53	50,98
A + G + H + I + N + O	0,000011	53,04	52,32	51,67	51,12
B + G + H + I + L + M	0,000001	50,46	49,86	49,34	48,90
B + G + H + I + L + N	0,000001	50,72	50,10	49,57	49,12
B + G + H + I + L + O	0,000001	50,50	49,87	49,33	48,87
B + G + H + I + M + N	0,000001	50,67	50,08	49,57	49,14
B + G + H + I + M + O	0,000001	50,44	49,84	49,33	48,89
B + G + H + I + N + O	0,000001	50,70	50,09	49,56	49,11
C + G + H + I + L + M	0,000005	49,80	49,24	48,77	48,37
C + G + H + I + L + N	0,000005	50,10	49,52	49,03	48,62
C + G + H + I + L + O	0,000005	49,84	49,25	48,76	48,34
C + G + H + I + M + N	0,000005	50,04	49,49	49,03	48,65
C + G + H + I + M + O	0,000005	49,77	49,22	48,76	48,36
C + G + H + I + N + O	0,000005	50,07	49,50	49,02	48,61
D + G + H + I + L + M	0,000005	49,80	49,33	49,14	48,37
D + G + H + I + L + N	0,000005	50,10	49,60	49,38	48,62
D + G + H + I + L + O	0,000005	49,84	49,34	49,13	48,34
D + G + H + I + M + N	0,000005	50,04	49,57	49,38	48,65
D + G + H + I + M + O	0,000005	49,77	49,31	49,13	48,36
D + G + H + I + N + O	0,000005	50,07	49,58	49,37	48,61
E + G + H + I + L + M	0,000001	49,80	49,25	48,79	48,37
E + G + H + I + L + N	0,000001	50,10	49,53	49,05	48,62
E + G + H + I + L + O	0,000001	49,84	49,26	48,77	48,34
E + G + H + I + M + N	0,000001	50,04	49,50	49,05	48,65
E + G + H + I + M + O	0,000001	49,77	49,23	48,77	48,36
E + G + H + I + N + O	0,000001	50,07	49,51	49,03	48,61
F + G + H + I + L + M	0,000001	50,98	51,78	52,36	50,59
F + G + H + I + L + N	0,000001	51,21	51,94	52,47	50,74
F + G + H + I + L + O	0,000001	51,01	51,78	52,35	50,57
F + G + H + I + M + N	0,000001	51,16	51,92	52,47	50,75
F + G + H + I + M + O	0,000001	50,96	51,77	52,35	50,58
F + G + H + I + N + O	0,000001	51,19	51,93	52,47	50,73

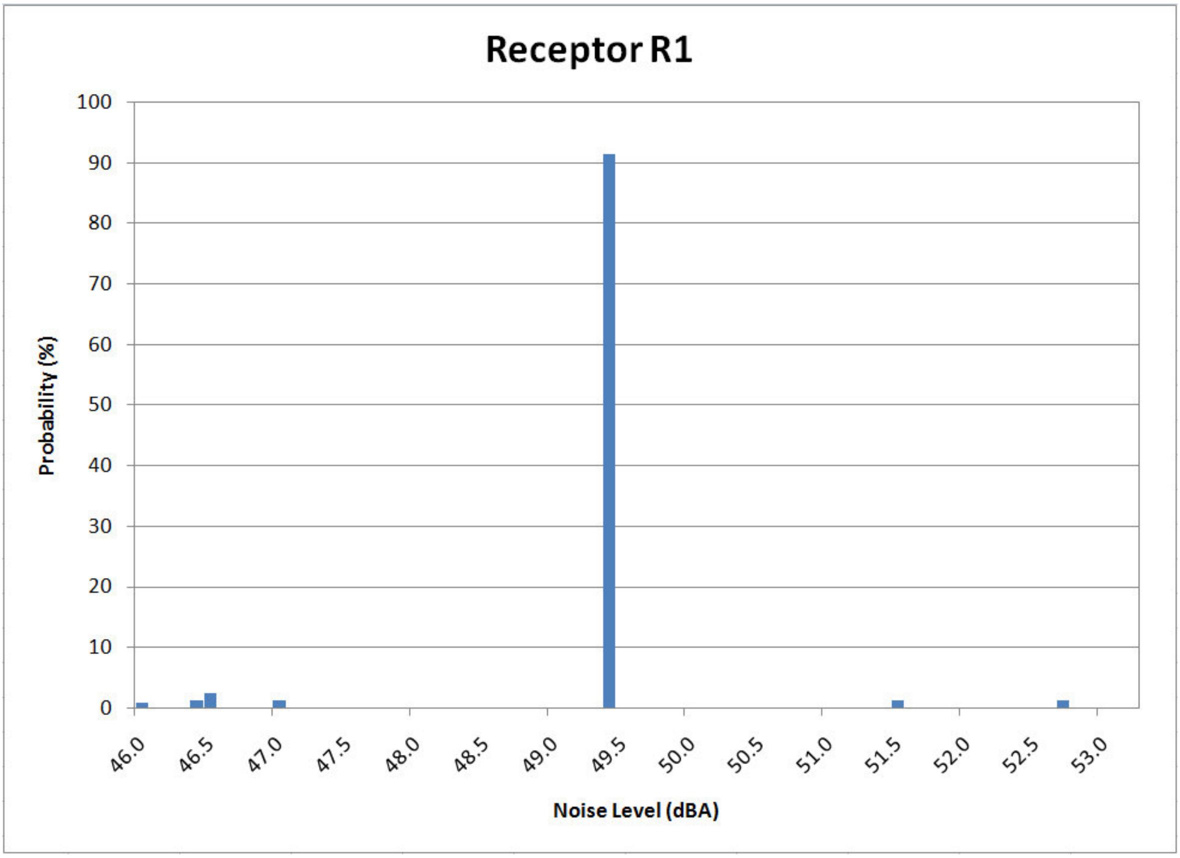

Figure 1. Statistical distribution of noise levels at the receptor R1.

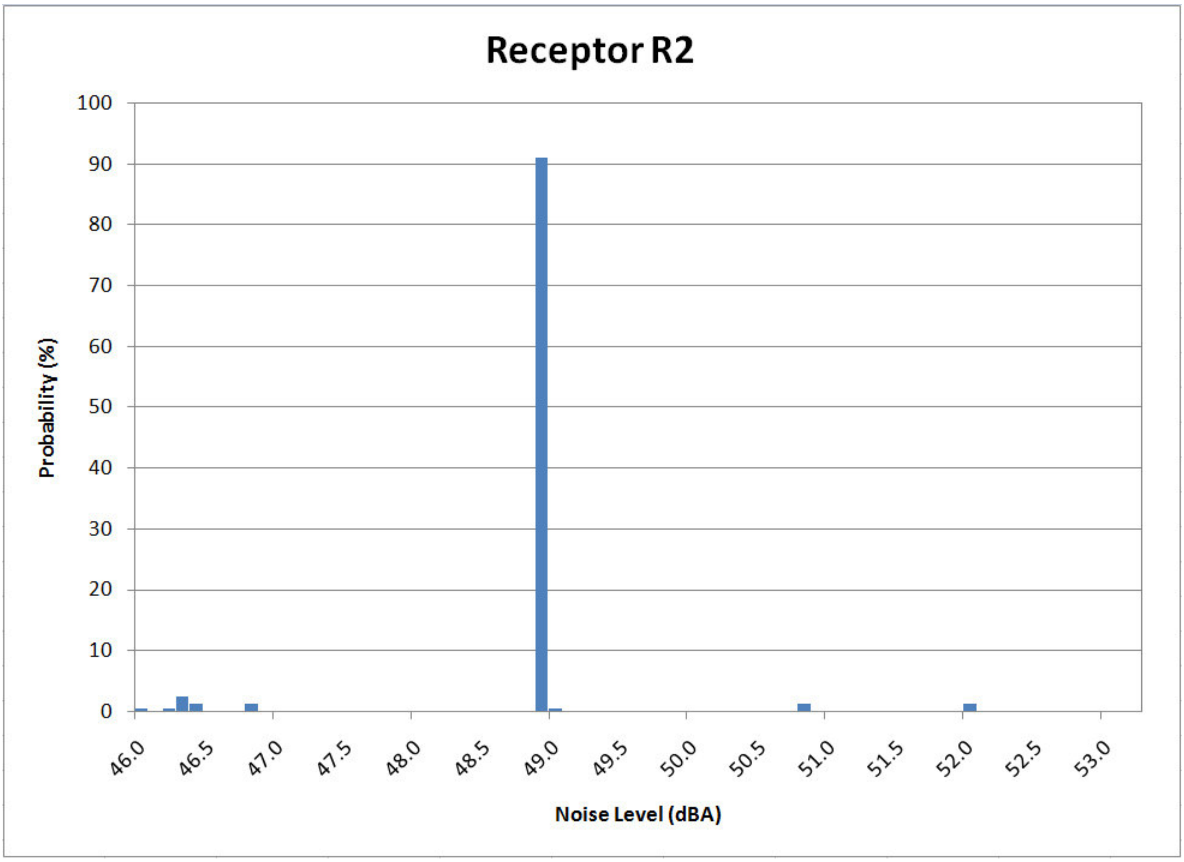

Figure 2. Statistical distribution of noise levels at the receptor R2.

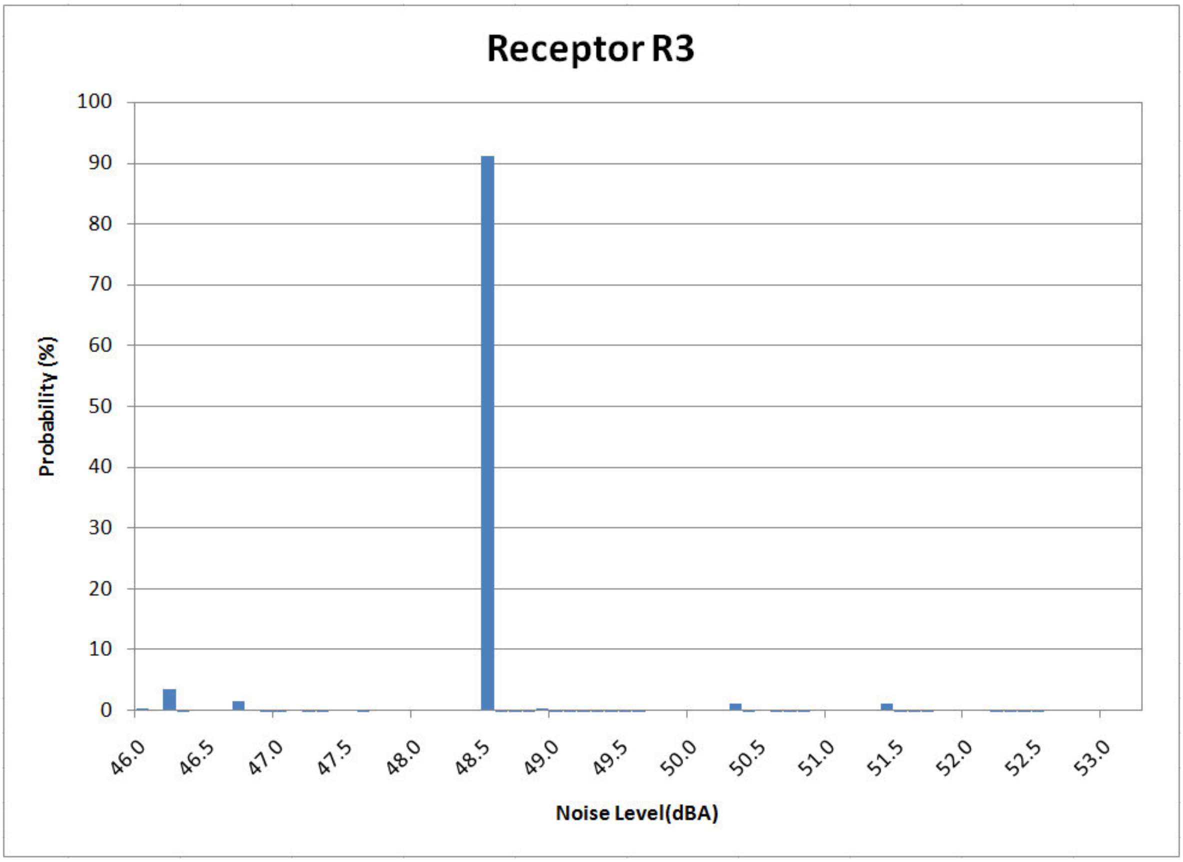

Figure 3. Statistical distribution of noise levels at the receptor R3.

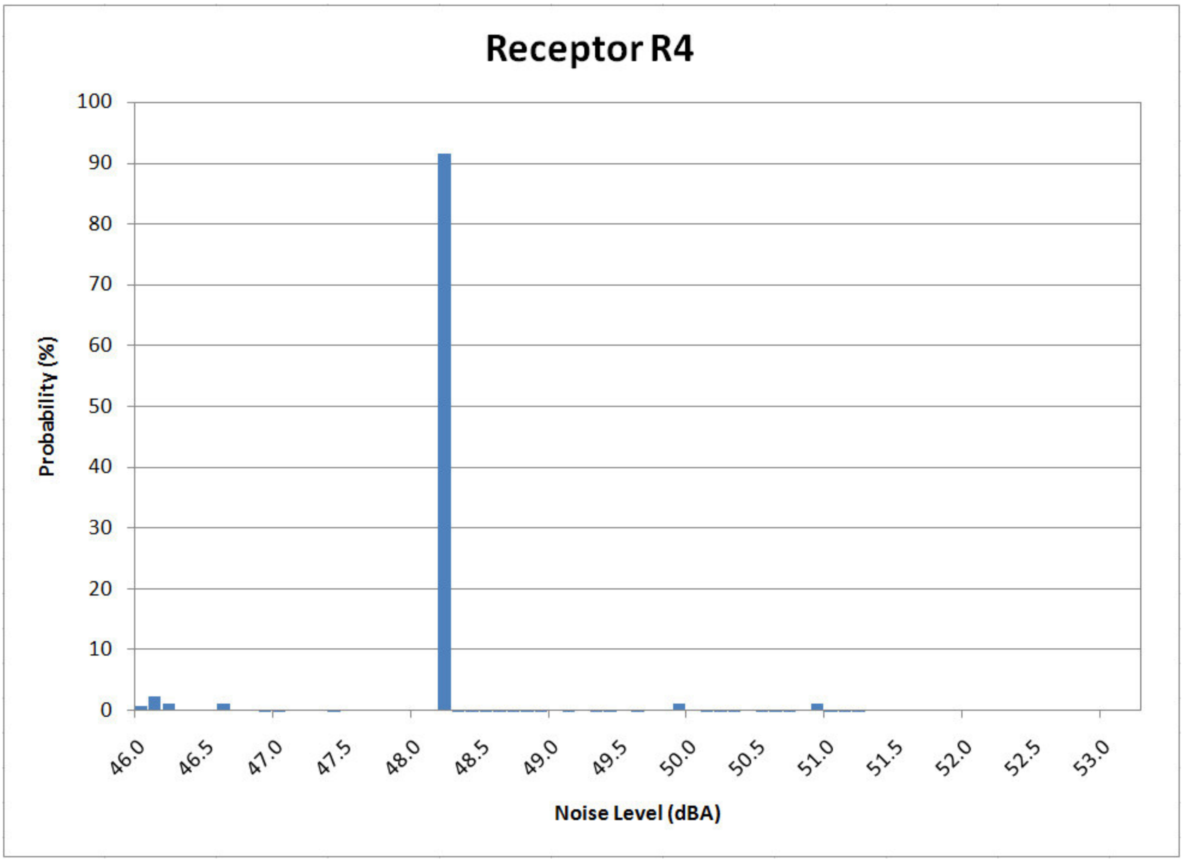

Figure 4. Statistical distribution of noise levels at the receptor R4.

Analysis of results shows that for each receptor there is a level with a high probability corresponding to the combination (preparatory controls of ropeway start-up and system inspection at runtime) which occurs at almost daily frequency. Such combination determines in the four receptors R1, R2, R3 and R4 respectively 49,5 dBA, 49,0 dBA, 48,5 dBA and 48,0 dBA.

5. Conclusions

In the present paper a new method is described to evaluate levels of disturb produced on receptors more exposed to maintenance, inspection and control (MPVC) activities of a light railway surface line.

Overcoming the uncertainty of all maintenance and control activities combinations, the presented methodology allows to identify the statistical distribution of noise levels on sensitive receptors.

Proposed method can be applied to other contexts where maintenance activities with different duration, frequency and acoustic emission level randomly combine within a reference time period.

At present time the model is under experimental validation phase with a measurement campaign of the noise produced by the infrastructure at the sensitive receptors.