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THE IMPACT ANALYSIS OF THE OBJECTIVE ACOUSTIC QUALITY PARAMETERS ON THE SUBJECTIVE ASSESSMENT OF SOUND CONTROL ROOM REVERBERATION

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Abstract: *This paper presents the research results obtained by measuring and assessment of professional sound control room. In this process all the features that these rooms have are taken into consideration and that is the fact that here the sound is reproduced through high quality professional equipment, and that listening area is only a small, exactly given place for optimal listening.*
The optimal sound control room must give completely clear perception of reproduced sound with all features, and the space as itself may not enter or change the characteristics of the reproduced sound. Also, the acoustic characteristics of the original recording room should be unchanged. This is obtained by creating very high quality sound control room, which includes designing, implementing and ultimately control measuring and testing.
Statistical Conjoint Analisys methods (CA) is statistical tool that shows which of the real, objective parameters of a test system has the greatest impact on the final subjective assessment or on the subjective decision of the respondents to the assessment of the system quality. In this work, a Conjoint Analisys method is used to obtain estimates of the impact of objective parameters of acoustic quality of the room on the subjective assessment of the reverberation time of the professional sound control room.
Thereby, the use of modern statistical method (CA) shows dependence of one subjective parameter on more objective parameters, which is much closer to the real situation. Realistically, all ratings are subject to some extent dependence on more objective parameters.

Key words: Sound Control Room, Impulse Response, Acoustic Qualitz, Subjective Parameters, Objective Parameters, Conjoint Analysis, Reverberation, Reverberation Time

1. INTRODUCION

The introduction presents an overview of the methods of objective measurement and subjective tests that have been used in the preparation of this paper.

1.1. Measurement method

Pulse measurement method is one of the basic measurements in the field of objective acoustical study of the room [1]. Since a transfer between two points in the room is linear, it is assumed that all the principles that are valid for linear systems can be automatically applied to acoustic room measurements. Analysis of the energy in the room is usually performed with a constant bandwidth percentage, generally by octave or one-third of octave.
The problem with pulse measurement of the room is to achieve an adequate signal/noise ratio, what is the reason why there are more ways of acoustical pulse room measurements.
Impulse response g (t) is a real function of time, and a unique description of the transfer function. Frequency spectrum, G (f) is related to the impulse response g (t) via the Fourier Transform. The G (f) is a complex function:

$$G(f) = \int_{-\infty}^{\infty} g(t) e^{-j2\pi f t} dt \qquad (1)$$

The signal that comes in the point of receipt p (t), is corresponding to the convolution of the impulse response and the source signals s (t):

$$p(t) = g(t) * s(t) \qquad (2)$$

$$P(f) = G(f) * S(f) \qquad (3)$$

where:

P (f) is the spectrum of the received signal
S (f) is the spectrum of signal source

Impulse response g (t) refers to the response to an idealized Dirac excitation pulse, which has a wide spectrum with uniformly distributed energy. In practice, it is impossible to achieve an ideal Dirac pulse, and the pulse energy is proportional to the pulse length. Quite short pulses that have a wide frequency range, but have small energy with which it is difficult to achieve adequate signal/noise ratio.
Impulse response of the room allows specification of individual strong reflection.
However, it is difficult to establish a link, correlation, between the representation of the impulse response and subjective assessments of room.
To measure with the impulse method corresponding signals that meet the following criteria have to be used:

- sufficient energy
- uniform wide spectrum.

The actual measurements were carried out in two ways – single channel and binaural, i.e. with single measurement microphone and with an artificial head, which were put in place in the room and the height corresponding to the usual place for listening, or the optimal place for listening. Since it is desirable to reduce possible measurement error to a minimum, each measurement has been done five times, and as the final result the mean value of each measured parameter is used. Before the final five measurements to be one pre-testing has been made. The duration of the signal is 5.5 s, and the sampling frequency is 48 kHz. In such way for each measurement 262144 signal samples are obtained.
In the measuring process, the microphone and the artificial head are located at the height of 1.40 m above the floor, right in the place where would normally sit "sound engineer". The artificial head was always in the same position relative to the sound source and the microphone is always in the median plane at the height of artificial ears.

1.2. Subjective assessments of the room

Subjective tests were made using a questionnaire that determined the 18 questions, the last of which provides an answer to an inquiry about the overall acoustic impression of space. Subjective assessment is made by the persons who are professionally engaged in the processing and sound production, as well as persons who have big knowledge and education familiar with the problems of acoustic qualities of the room and quality of listening.

Subjective tests are always performed under unique defined and calibrated conditions, where the defined sound pressure of frequency f=1 kHz at a distance of 1 m from the monitor's speaker in its central axis is 90 dB [2], [3], [4], [5].

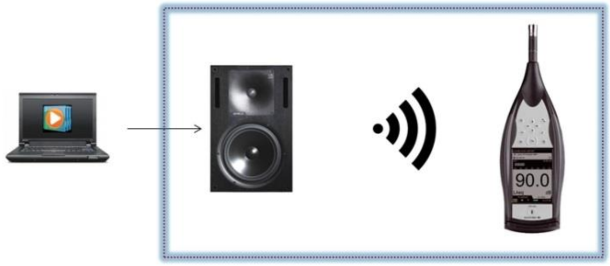

Fig. 1. Calibration of the system for subjective testing

2. ANALYSIS OF SOUND CONTROL ROOM OBJECTIVE PARAMETERS OF ACOUSTIC QUALITY

Research and analysis of the measured objective parameters and subjective assessed parameters of acoustic qualities of the room were made on a total of 6 sound control rooms of Croatian Radio, Croatian Radio and Television, as follows:

- Sound Control Room R1 and R4 - multichannel music control room
- Control room R5 – speech and music control room
- Sound Control Room R13 – control room for audio editing
- Sound Control Room R11 – big control room of studio Bajsić
- Sound Control Room R12 – small control room of studio Bajsić

Listed professional sound control rooms have a minimum floor area of 25.9 m^2 to a maximum of 46.20 m^2, with an appropriate volume of at least 75.11 m^3 to a maximum of 157.08 m^3, which corresponds to the average and standard sizes of professional sound control rooms. All rooms are appropriately acoustically treated, insulated from outside noise, connected through the window with the studio area, and are equipped with special doors that meet the needs of acoustic insulation from outside noise.
In each room a mixing console is placed in acoustically optimal part of the room, and sound is listened through professional loudspeaker systems.
Analysis of the measured objective parameters of acoustic quality of sound control room includes analysis of the results across all frequencies of measured frequency band from 125 Hz to 8 kHz. With the statistical method PCA - Principal Component Analysis it is determined under what conditions the most accurate measurement results are obtained.
It is a statistical method [6], [7] which combines a large number of variables (results) to new, virtual variables,

which incorporate all existing and actually measured, but their number is far lower than the actual. In this analysis, the number of components is limited to two (PC1 and PC2) and it is found what actual measurements, and measurement conditions have the greatest effect only on the first two components. Selecting those two main components only the biggest impact of actual results is analyzed. With those results the further Analisys has been made.

3. ANALYSIS OF SOUND CONTROL ROOM SUBJECTIVE PARAMETERS OF ACOUSTIC QUALITY

Subjective assessments of professional sound control rooms were performed using specially designed questionnaires which participants completed while listening to specially prepared musical material given in Table 1, for a total of 16.5 minutes, which covered all the areas essential for a correct subjective assessment of the room.

(1) Noise volume
- External noise level in the room intended for general listening is a measure of acoustic insulation of walls and all openings (doors, window openings and installation)
- Internal noise level in general is a measure of the acoustic attenuation of internal noise sources (ventilation, forced cooling of lighting devices, device noise in the room)

(2) Intimacy, Presence
- The property that the room has a good response to the sound of instruments and that musicians are well able to clearly hear the other musicians in the orchestra

(3) Loudness

(4) Revereberance
- Non-uniform reverberation time within certain frequency range directly affects the color of the tone

(5) Tonal Reproduction, Timbre
- Acoustic characteristics of room can cause different changes in the spectrum of the signal in each particular part of the audio process (steady state, the initial and final transient)

(6) Sound Definition, Clarity
- The possibility to distinguish different musical instruments or musical sounds
- Audibility of the initial transients

(7) Echo Disturbance
- Perceived in the case when isolated sound wave comes to the ears of listeners with a delay of more than 1 / 15 s (67 ms) compared to the arrival of direct sound

(8) Speech Intelligibility
- It is necessary to ensure the preservation of the natural color of the speaker's voice or sound in generally, to identify the speaker or sound source, or to enable and provide artistic experience

(9) Spectral Uniformity, Balance
- The direct impact to the quality is the establishment of standing waves and resonance frequencies of the room

(10) Sound stage imaging
- It depends on the amount of reflected sound energy compared to direct sound energy during the early decline in sound pressure at the point of receipt
- Important by stereophonic and multichannel reproduction

(11) Dynamics
- Determined by the minimum and maximum volume level and the possibility of transferring the original dynamics

(12) Distortion
- The consequence of the big mistakes in the design and construction of the room intended for listening to speech and music
- Reflected in the change of color and sound enhancement or suppression of certain frequencies or frequency ranges

(13) Stability of performance
- It determines an equal volume in the whole room (auditorium)
- At frequencies of wavelength in the order of the width of the spacing between the ears directly affects the perception of spatial sound image
- The establishment of standing waves in the room and the resonant frequency directly affect to the achievement of a uniform distribution of sound pressure and to the achievement of distinct areas of minimum and maximum sound pressure level which distance is the frequency dependent

(14) Brilliance
- Representation of high frequencies at the receiving point

(15) Bass reproduction
- Representation of low frequencies at the receiving point

(16) Resonance
- The phenomenon on a certain frequency or frequencies when the room, windows, screens or other parts or structures in the room began to vibrate and thereby produce unwanted sound - noise
- The result of insufficient anchorage or high elasticity of individual parts or structures

(17) Ambience Reproduction, Diffusion
- The possibility of reproducing the original room (space) where the music was recorded in some other enclosed space, or the harmony of the room acoustic parameters with the sort of sound (music or speech).

(18) Overall Acoustic Impression.

Values (marks) on the questionnaire were discrete in the range of 1 to 5, whereby 1 is the worst and 5 the best result. It was taken into account that in some cases the two extremes can be assessed as bad or worst. For example, the reverberation time can be rated as poor even if it is too large, even if it is too short. The same situation as the example is the volume of music which can be bad even if it is too loud or too quiet. The best results are in the case of optimum reverberation time or comfort sound level. In the case of unique results assignment, such as in the case of dynamics, descriptive marks are uniquely assigned to numerical values, whereby, for example, the dynamics best score is in the case of the maximum dynamics.

Table 1. The content of audio test CD

1.	Orff	Choir (Carmina Burana)	30 s
2.	Mozart	Soprano (Cotrubas, Der Hölle Rache – The Magic Flute)	30 s
3.	Orff	Baritone (Carmina Burana, Hakan Hagegard)	30 s
4.	Beethoven	Double Bass (9th Symphony, Presto)	30 s
5.	Dvorak	Percussion (9th Symphony, Scherzo)	20 s
6.	Mozart	Strings (Divertimento KV 251, Andantino)	42 s
7.	Chopin	Piano (4th Ballad)	30 s
8.	Mussorgsky	Full Orchestra (Night on the bare mountain)	30 s
9.	Williams	Return of the Jedi	1 min
10.	Rodrigo	Concerto d'Aranjuez, Adagio	1 min
11.	Beethoven	9th Symphony, Presto	1 min
12.	Rachmaninov	Prelude	1 min
13.	Dvorak	9th Symphony, Scherzo	1 min
14.	Strauss	Salome	1 min
15.	Vivaldi	Winter, arr, for three guitars	1 min
16.	Orff	Carmina Burana	1 min
17.	Mozart	Divertimento KV 251, Andantino	1 min
18.	Ravel	Bolero	1 min
19.	Mussorgsky	Night on the bare Mountain	1 min
20.		Speech – male voice	20 s
21.		Speech – male voice	20 s
22.		Speech – female voice	20 s
23.		Speech – female voice	20 s

In this way were obtained subjective ratings of 18 parameters (among all others reverberation) for all the professional sound control rooms in which objective parameters of acoustic quality were measured.
The range for each parameter in the studied areas extends from a minimum value of 1, which is very rare, but exist, and in most cases, to a score of 5 in the generally higher rated sound control room. However, the borderline case value of 1 (the worst case) could be considered as borderline cases, and so could be so treated and discarded, in all research analysis the borderline cases are also taken into account and all analyzes were made with all results of assessment, without any rejection [8], [9], [10], [11].

4. ASSESSING THE IMPACT OF OBJECTIVE PARAMETERS OF ACOUSTIC QUALITY OF THE ROOM ON THE SUBJECTIVE ASSESSMENT

The problem in assessing the impact of objective parameters of acoustic qualities of the space on the subjective assessment is that there is their mutual dependence, but also a very large number of parameters which are mutually dependent, and if we assume that we have a matrix with the values of objective parameters [X] and other matrix values of subjective ratings [Y], we know that there must be mutual linear dependence of these two matrices, and we can say that:

$$[Y] = [k] * [X] \qquad (4)$$

Unfortunately, with classic and simple mathematical operations coefficient matrix [k] cannot be obtained as the quotient of matrix [Y] and [X], i.e.

$$[k] \neq \frac{[Y]}{[X]} \qquad (5)$$

A statistical method CA - Conjoint analysis [14], [15], [18] is a statistical tool that shows which one of the real, objective parameters of a tested system has the greatest impact on the final subjective assessment or subjective decision of respondents on the assessment of the quality of the system [12], [13].
In this study, the Conjoint analysis statistical method was used to obtain estimates of the impact of objective parameters of acoustic quality of the room on the evaluation of the subjective parameters of acoustic quality.
For this purpose, orthogonal matrix with objective parameters of acoustic quality and their actual measured values is defined. In this article the values for reverberation time parameters EDT, T_{10}, T_{20} and T_{30} are considered.

Table 2. Objective parameters used when creating a matrix for analysis

OrtMat_01	EDT	RT_{10}	RT_{20}	RT_{30}

OrtMat_01 contains the values of objective parameters related to a reverberation time EDT, RT_{10}, RT_{20} and RT_{30}. Analysis with this matrix gives the dependence of the results of subjective assessment of the different reverberation times that are used for estimating and calculating the reverberation time.

The model for Conjoint analysis is as follows:

Table 3. Model description

	N of Levels	Relation to Ranks or Scores
EDT	3	Linear
T10	4	Linear
T20	4	Linear
T30	5	Linear

The coefficient of impact [14] was analyzed for each subject, which gave a further insight into dependence of subjective assessments, and confirmed the fact that the subjective rating is an extremely complex process, which among all depends on the personal preferences of the respondents. A higher value of the coefficient means greater significance of the impact of a particular parameter on the subjective assessment.

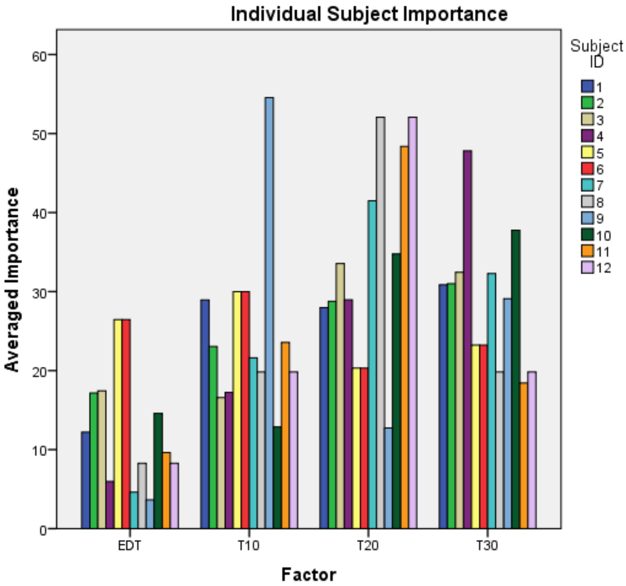

Fig. 3. The impact of each parameter for each subject separately

However, analysis of the effect of each parameter on each of the subjects showed that the impact is generally within the expected limits. At the end a relevant result takes only the overall coefficient of influence of each parameter of the objective to the subjective evaluation. In particular, from a graph above it is possible to see that the most influential parameter is RT_{20}. Especially, it is possible to see that for the impact of parameter RT_{10} there is only one subject for which is obviously the most important parameter RT_{10}.

Table 4. Importance value

EDT	12,893
T10	24,840
T20	33,449
T30	28,817

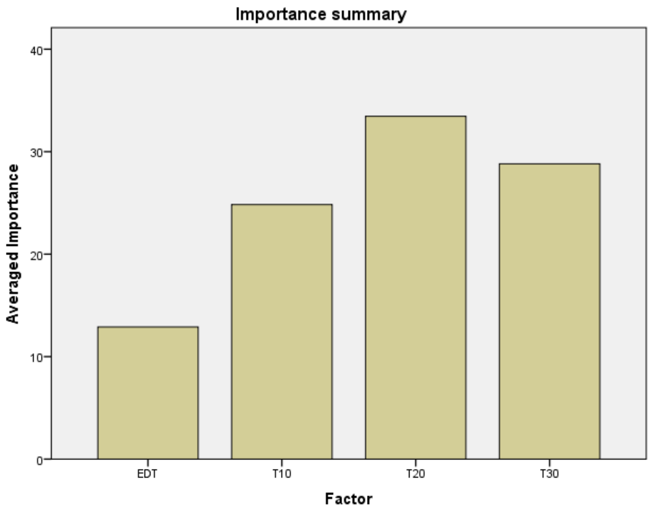

Fig. 4. Total coefficient impact for each parameter

5. CONCLUSION

In the process of evaluating the acoustic quality in general is always a problem to determine the correlation between the measured objective and assessed subjective parameters of observed room. In our research "the units under the test" were professional sound control rooms of Croatian Radio, Croatian Radio and Television.

In this research as the results of measuring and testing there is a matrix of results, which included the value of objective and subjective parameters of acoustic room quality for those professional sound control rooms. Since there is no direct option of calculating the coefficients of influence of each parameter of the objective acoustic quality to the subjective assessment, a mathematical analysis using statistical Conjoint analysis method was used. Thus, coefficients of estimated impact of certain objective parameters related to reverberation time EDT, RT_{10}, RT_{20} and RT_{30} to the values of subjective parameters of acoustic quality related to subjective parameter reverberation are given. Those results show that the most important objective parameter for subjective parameter reverberance is the objective parametar related to reverberation time RT_{20}.

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