Concert Hall Acoustics: Paper ICA2016-502

Rank-ordering opera houses according to their sound quality parameters using PROMETHEE II method

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Abstract:

Classifying sound quality in opera houses is a difficult task, as it depends on several subjective and objective parameters. The aim of this work is to create and evaluate a method for objective rank-ordering of Opera Houses and to compare it with the subjective rank-ordering procedure proposed in Hidaka and Beranek, J. Acoust. Soc. Am. 107, 368-383 (2000). This problem was solved using a multi criteria decision making method, called PROMETHEE II. This article describes its implementation and presents experimental results which are compared with subjective results presented in Hidaka and Beranek (2000). In addition, PROMETHEE II was used to classify 9 opera houses which had not been ranked in Hidaka and Beranek (2000). The results obtained show that the objective rank ordering created using PROMETHEE II which is based on objective parameters can successfully replace the subjectively based procedure of Hidaka and Beranek (2000). Four of the top six ranked opera houses were correctly classified and the performance can still be improved by means of optimization methods currently under investigation.

Keywords: opera house, sound quality parameters, PROMETHEE II, objective rank-ordering

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1 Introduction

Classifying acoustic quality is not an easy task, for it depends on many subjective and objective parameters. An attempt to figure out which acoustical qualities concertgoers would prefer usually elicits recollections about particular concerts that gave them great and amazing experiences. For those listeners many elements come together to yields enjoyment – the composition, the conductor, the orchestra, and the hall, among others, must combine properly in order to provide a memorable listening experience. For the musicians and acoustical engineers it is of interest to identify the parameters which distinguish the acoustic quality in a music performing space [1].

The acoustical properties of an opera house (OH) are strongly influenced by its constructive characteristics, e.g. the reflecting surfaces near the proscenium (audience side) and the balcony fronts and the ceiling surfaces must be shaped to send early reflections uniformly to all parts of the audience [1].

Some subjective parameters might be represented by objective parameters to which is assigned a numerical representation of the acoustical aspects which give us an idea on how good the sound is in a place. In some cases subjective parameters cannot be represented by a number.

[4] created a subjective and objective rank-ordering (SRO and ORO) and used them for twenty three opera houses by. Subjective rank-ordering was implemented by applying questionnaires and interviews to conductors.

Even though the objective one depends on many parameters, like reverberation time (RT) and the binaural quality index (BQI), which classifies the problem of a Multi-Criteria Decision Aid (MCDA). The MCDA often deals with ranking of many concrete alternatives from the best to the worst ones based on multiple conflicting criteria [2].

The idea of this paper is to propose a rank-ordering method based on the data of the objective parameters and to compare its results with the subjective rank-ordering. The problem was solved using Multi Criteria Decision Making Method PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluations) which was implemented in Matlab. PROMETHEE II has been chosen because it provides a complete ranking without incomparability [3].

This paper presents the parameters used to describe Opera Houses and SRO made by [4] used to classify 23 OH around the world. But out of the 23 opera houses, only 13 of them showed their SQP in [1], thus the paper consider a SRO with 13 OH. Afterwards, it shows the characteristics of the implementation of PROMETHEE II. The result of objective ranking using PROMETHEE method was compare to Hidaka et al (2000) study. Through this comparison was possible to verify that 4 OH had the some ratings and 5 of them had similar ratings.

After validating this method, it was included in ORO 9 others Opera Houses which had acoustical available and were not included at [4] survey.

It was possible conclude that PROMETHEE II method can be utilized to rank OH and it has great advantage because it is easier to implement than subjective rank-ordering by applying questionnaires.

2 Methodology

2.1 Sound quality parameters (SQP)

The Sound Quality Parameters used for the implementation of the PROMETHEE II are described below in accordance with [1] and [4].

2.1.1 $RT_{occ,M}$

Reverberation Time is the number of seconds that a loud sound takes to decay 60 dB after being stopped in a hall fully occupied at middle frequencies (between 350 and $1400Hz$).

2.1.2 $EDT_{unocc,M}$

Early Decay Time is the exact amount of time it takes for a sound from a musical note to decay $10dB$ after it is cut off, multiplied by a factor of 6 in an unoccupied hall at middle frequencies. It designates that initial phase of sound decay.

2.1.3 $C_{80,3}$

Clarity factor, expressed in dB, is the ratio of the early energy $(0-80ms)$ to the late (reverberant) energy $(80-3000ms)$. The horizontal clarity, related to tones played in succession, refers to the degree to which sounds that follow one another stand apart. Usually, the published value is the average of the C_{80} values in the $500-$, $1000-$ and $2000-Hz$ octave bands and at a number of seats in a hall.

2.1.4 G_{125} e G_M

Strength factor is a measure in dB for the sound pressure level (SPL) at a point in a hall with an omnidirectional source on stage, minus the SPL that would be measured at a distance of $10m$ from the same sound source operating at the same power level and located in an anechoic chamber. The difference with them is that G_{125} is measured in the $125Hz$ band, an the other by the average of 500 and $1000Hz$ bands.

2.1.5 BQI

Binaural Quality Index is a measure of the differences in the musical sounds that reach the two ears within $80ms$ after the arrival of the direct sound. The BQI is defined as $(1-IACC_E)$, where $'E'$ designates early sound, and $'3'$ indicates the average of the $IACC_E$ values in the 500, 1000

and $2000Hz$ bands.

2.1.6 $ITDG$

Initial-Time-Delay Gap is the time in milliseconds determined by the first sound reflection from a side wall or a balcony front after arrival of the direct sound.

2.2 Subjective rank-ordering (SRO)

The procedure described in [4] to compare and rate 24 opera houses was carried out using questionnaires which were mailed to many important opera conductors. They were asked for ratings of the acoustics of the opera halls that the conductors knew well on scales that had five steps, grading them from 1 to 5. Some of the opera halls do not have their sound quality parameters available in [1] or fewer than 6 conductors rated them, therefore they were not considered in this paper. The other ones are shown in Table 1.

Table 1: **Subjective rank-ordering**

Rating	Opera House	Symbol
1	Teatro Colón, Buenos Aires	BA
2	Semperoper, Dresden	DS
3	Teatro alla Scalla, Milan	MS
4	New National Theater, Tokyo	TT
5	Opéra Garnier, Paris	PG
6	Staatsoper, Prague	PS
7	Staatsoper, Vienna	VS
8	Metropolitan Opera, New York	NM
9	Festspielhaus, Salzburg	SG
10	Staatsoper, Hamburg	HS
11	Deutscheoper, Berlin	BD
12	Civic Opera, Chicago	CC
13	Komischeoper, Berlin	BK

2.3 Objective rank-ordering using PROMETHEE II

[1] shows the measurement of the sound quality parameters for 22 opera houses around Europe, Japan, and the Americas, and these data was utilized as parameters in the implementation of the problem. This part of the paper describes how the PROMETHEE II was implemented, and which were the considerations assumed to model and to solve the problem.

2.3.1 PROMETHEEII

Figure 1 illustrates how PROMETHEE II has been implemented by [2]. More information about this method can be found in [3].

The deviations based on pair-wise comparisons were calculated based on the fact that here is no ideal acoustic.

Step 1. Determination of deviations based on pair-wise comparisons

$$d_j(a,b) = g_j(a) - g_j(b) \qquad (1)$$

Where $d_j(a,b)$ denotes the difference between the evaluations of *a* and *b* on each criterion.

⬇

Step 2: Application of the preference function

$$P_j(a,b) = F_j[d_j(a,b)] \qquad j=1,\dots,k \qquad (2)$$

Where $P_j(a,b)$ denotes the preference of alternative *a* with regard to alternative *b* on each criterion, as a function of $d_j(a,b)$.

⬇

Step 3: Calculation of an overall or global preference index

$$\forall a,b \in A, \qquad \pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j \qquad (3)$$

Where $\pi(a,b)$ of *a* over *b* (from 0 to 1) is defined as the weighted sum $p(a,b)$ of for each criterion, and w_j is the weight associated with *j*th criterion.

⬇

Step 4: Calculation of outranking flows/ The PROMETHEE I partial ranking

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \quad (4) \quad \text{and} \quad \phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a) \quad (5)$$

Where $\phi^+(a)$ and $\phi^-(a)$ denote the positive outranking flow and negative outranking flow for each alternative, respectively.

⬇

Step 5: Calculation of net outranking flow/ The PROMETHEE II complete ranking

$$\phi(a) = \phi^+(a) - \phi^-(a) \qquad (6)$$

Where $\phi(a)$ denotes the net outranking flow for each alternative.

Source: Behzadian et. al, 2009

Figure 1: **Stepwise procedure for PROMETHEE II**

[1] contains another subjective rank-ordering, and about that the author says that he does not recommend the use of the his own list by any party for purposes of comparing halls other than for research, or claiming that any given hall is supe-rior or inferior to another. This observation can be extended to the list showed in Table 1, however acoustical parameters of Teatro Cólon in Buenos Aires were used as ideal values to classify other halls because it had the best evaluation in the questionnaires.

Each criterion g_j in $Step1$ was calculated by the absolute value of the difference between the acoustical parameter of BA and the respective parameter of the opera house. For example, the criterion for the $RT_{occ,M}$ of DS opera house is given by:

$$g_1(DS) = |RT_{occ,M(BA)} - RT_{occ,M(BA)}| = |1.56 - 1.60| = 0.04 \qquad (1)$$

These data were obtained in [1], which contains a table with objective measurements of the sound quality parameters described in section 2.1 for 23 opera houses. Royal Opera House was disregarded because there was one missing data for $EDT_{unocc,M}$.

The Figure 2 shows the results for the criteria 1 to 7 of each opera houses, which refers to $RT_{occ,M}$, $EDT_{unocc,M}$, $C_{80,3}$, G_{125}, G_M, BQI and $ITDG$.

The multicriteria problem was to classify the opera houses according to that which has the values of the acoustical parameters nearest to BA.

2.3.2 $Step1$

The calculus of d_j denotes the difference between the evaluations of 2 opera houses in each criterion, as shown in equation (2):

$$d_1(DS,MS) = g_1(DS) - g_1(MS) = -0.28 \tag{2}$$

2.3.3 $Step2$

The application function was applied considering a Gaussian Criteria described in [3]. It was used $\sigma = 0.5$, then:

$$P_j(a,b) = \begin{cases} 0, & \text{se} \quad d_{j(a,b)} \leq 0, \\ 1 - \exp(\frac{d^2_{j(a,b)}}{0.5}), & \text{se} \quad d_{j(a,b)} > 0. \end{cases} \tag{3}$$

2.3.4 $Step3$

The calculus of an overall preference index was applied as shown in $Step3$ considering the weight of each criterion: $[w_1\, w_2 \dots w_7] = [1\,1\,1\,1\,1\,3\,2]$

The weight of the parameters 6 and 7 is higher than others ones because in the [4] analysis the BQI parameter has the greatest correlation with the acoustical quality of the halls, and following it, $ITDG$ most closely correlates with the ratings.

2.3.5 $Step4$

The calculus of positive and negative outranking flows was done as shown in $Step4$ of Figure 1. It means that the larger the $\phi^+(a)$, the more a dominates the other action. And the smaller the $\phi^-(a)$, the less a is dominated [3].

2.3.6 $Step5$

In this case, the smaller the value of net outranking flow $\phi^(a)$, the better the acoustical parameters the opera house a has.

3 Results

The steps described above were implemented in $Matlab$ looking upon the 21 opera houses shown in Figure 2 with their 7 criterion, and an analysis is described in the following items.

	Hall Name	g_1	g_2	g_3	g_4	g_5	g_6	g_7	SROP
DS	Semperoper, Dresden	0.0400	0.1100	0.3000	0	0.3000	0.0700	2	2
MS	Teatro alla Scalla, Milan	0.3200	0.5800	2.5000	0.6000	2.7000	0.1700	2	3
TT	New National Theater, Tokyo	0.0700	0.0200	0.5000	0.4000	0.7000	0	2	4
PG	Opéra Garnier, Paris	0.3800	0.5600	3.5000	0.6000	1.7000	0.1500	3	5
PS	Staatsoper, Prague	0.3300	0.5500	2	0.3000	0.2000	0.0100	2	6
VS	Staatsoper, Vienna	0.2000	0.2900	1.6000	0.4000	0.4000	0.0500	1	7
NM	Metropolitan Opera, New York	0.0900	0.1000	0.6000	0.4000	1.9000	0.0300	0	8
SG	Festspielhaus, Salzburg	0.0600	0.0800	0.4000	0.4000	1.2000	0.2500	9	9
HS	Staatsoper, Hamburg	0.3300	0.3700	1.1000	0.5000	1.1000	0.1900	16	10
BD	Deutscheoper, Berlin	0.2000	0.1200	0.4000	0.1000	1.2000	0.2600	15	11
CC	Civic Opera, Chicago	0.0500	0.2300	1	0.1000	2.1000	0.1200	23	12
BK	Komischeoper, Berlin	0.3100	0.4900	2	0.3000	3.6000	0.0300	2	13
AM	Music Theater, Amsterdam	0.2600	0.4200	0.8000	0.2000	0.7000	0.1000	14	-
BE	Erkel Theater, Budapeste	0.2600	0.3200	2.7000	0.4000	0.9000	0.2000	1	-
BS	Staatsoper, Budapeste	0.2200	0.3500	0.8000	0.5000	2.0000	0	3	-
EO	Opera House, Essen	0.0500	0.1800	0.2000	0.2000	2.8000	0.1100	2	-
RE	Eastman Theater, Rochester	0.0700	0.1800	0.3000	0.3000	1.2000	0.1100	4	-
SO	Opera House, Seattle	0.4600	0.7800	1.5000	0.9000	0.3000	0.1700	7	-
TB	Bunka Kaikan, Tokyo	0.0500	0.0300	0	0	2.1000	0.0900	4	-
NT	Nissei Theater, Tokyo	0.4600	0.6600	3.3000	0.5000	2.9000	0.0700	1	-
WJ	Opera House, Washington	0.2800	0.4500	3.2000	0.6000	0.7000	0.1200	3	-

Figure 2: **Criteria for 21 Opera Halls ($g_1 - g_7$) and its subjective rank-ordering position (SROP)**

3.1 Comparing the subjective rank-ordering (SRO) with the objective rank-ordering using PROMETHEE II (OROPII)

Figure 3 shows the Net Outranking Flow ($\phi()$) for the Opera Houses in SRO containing the acoustical parameters.

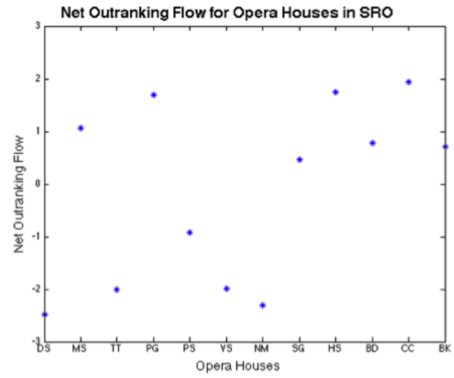

Figure 3: **Net Outranking Flow ($\phi()$) for Opera Houses in SRO**

The Opera House DS had the smallest value for ($\phi()$), that means it was the best evaluated OH followed by NM and TT. The highest value was calculated for CC, and following it appeared HS and PG in sequence, and they were the worst evaluated OH.

The Opera House BA did not appear in Figure 3 because it was the acoustical parameters reference's, and for the purpose of this method, it had the first position in the ranking.

Figure 4 gives a comparison of the positions in the rank-ordering between SRO and OROPII. There were 4 OH with the same rating (BA, DS, TT and PS), 5 with similar positions (VS, SG, HS, BD and CC) and 4 with disparate values (MS, PG, NM and BK).

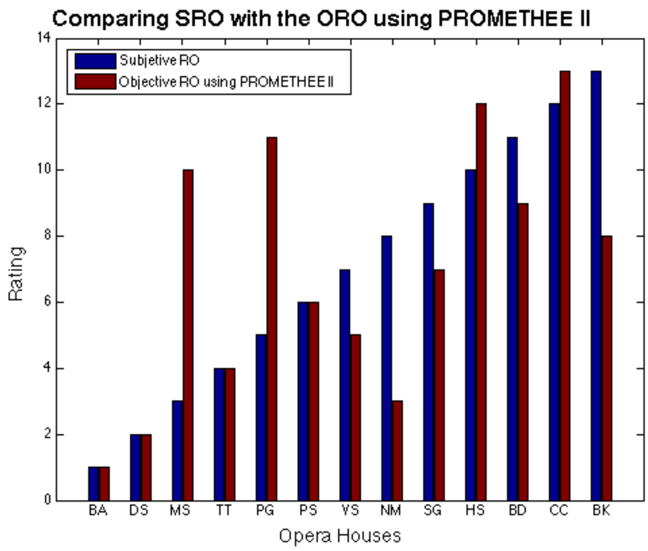

Figure 4: **Comparing SRO with OROPII**

The error between the positions was evaluated using the equation 4:

$$e_{\%} = \sum_{i=1}^{N_{OH}} \frac{|r_{SRO}(i) - r_{OROPII}(i)|}{N_{OH}} \tag{4}$$

where:

$r_{SRO}(i)$	SRO rating for the ith OH
$r_{OROPII}(i)$	OROPII rating for the ith OH
$N_{OH}(i)$	number of OH's (in this case $N_{OH} = 13$)

For the differences shown in Figure 4, equation (4) had the value: $e_{\%} = 18.9\%$

This value is acceptable because there is no ideal rating for Opera Houses, and the SRO is just a reference. For the same reason, there are no ideal acoustical parameters, and the SQP of BA was just the starting point for this research.

3.2 Objective Evaluation of 22 Opera Houses using the OROPII

Considering what was described in the section 3.1, the study was expanded to all opera houses containing the data of SQP available in [1].

Figure 5 shows the net outranking flow ($\phi()$) for the 21 OH's introduced in Figure 2.

The values of ($\phi()$) showed in Figure 5 were utilized to rank-order the 22 OH's with the SQP available in [1] in an increasing order and the result is presented in Table 2.

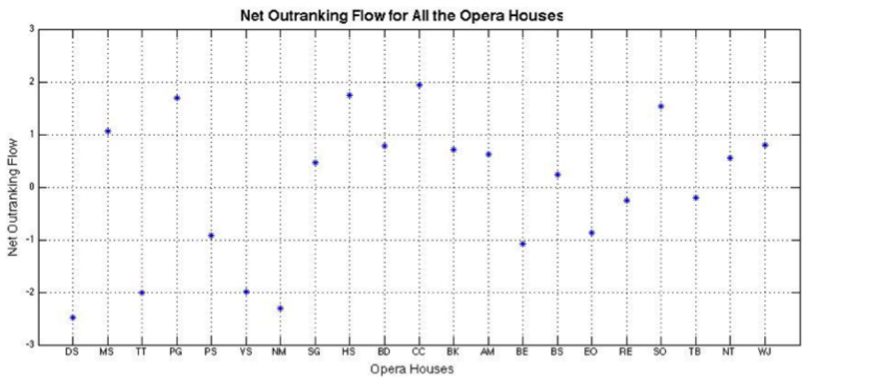

Figure 5: **Net Outranking Flow ($\phi()$) for the Objective Evaluation of 21 OH's**

Table 2: **22 Rank-Ordered Opera Houses using PROMETHEE II**

Rating	**Opera House**	$\phi()$
1	Teatro Colón, Buenos Aires (BA)	-
2	Semperoper, Dresden (DS)	-2.49
3	Metropolitan Opera, New York (NM)	-2.30
4	New National Theater, Tokyo (TT)	-2.00
5	Staatsoper, Vienna (VS)	-1.99
6	Erkel Theater, Budapeste (BE)	-1.08
7	Staatsoper, Prague (PS)	-0.92
8	Opera House, Essen (EO)	-0.86
9	Eastman Theater, Rochester (RE)	-0.26
10	Bunka Kaikan, Tokyo (TB)	-0.21
11	Staatsoper, Budapeste (BS)	0.24
12	Festspielhaus, Salzburg (SG)	0.47
13	Nissei Theater, Tokyo (NT)	0.55
14	Music Theater, Amsterdam (AM)	0.63
15	Komischeoper, Berlin (BK)	0.71
16	Deutscheoper, Berlin (BD)	0.78
17	Opera House, Washington (WJ)	0.79
18	Teatro alla Scalla, Milan (MS)	1.06
19	Opera House, Seattle (SO)	1.53
20	Opéra Garnier, Paris (PG)	1.70
21	Staatsoper, Hamburg (HS)	1.73
22	Civic Opera, Chicago (CC)	1.94

There are some ($\phi()$) values near each other (i.e. BK, BD and WJ), that means a different approach for the type of $P_j(a,b)$ (equation (3)) and the values of weights ($Step3$) can easily modify the positions of the OH's in the evaluation showed in Table 2.

4 Conclusions

The beauty of an operatic performance in an Opera House depends on a number of factors in addition to acoustics (the voice and personality of the singers, the beauty of the orchestral, the costume and scenery design, and the view of the stage [4], so it is not possible to consider all these factors, but it was shown that there is a relation between the sound quality parameters and how good the OH is.

The method proposed in this paper classifies the Opera Houses according to their sound quality parameters using PROMETHEE II. This method could be validated because 4 of the 13 OH's considered here have the same ratings and 5 of them had similar ones comparing them to SRO made by [4], considering an error between the positions of 18.9% $(e_{\%})$.

Just as the study shown in [1] the objective ranking-ordering presented in this paper should not be used to determine whether or not an OH is in any way better than another from the acoustical point of view. The ranking method presented in this paper is not better or worse than the subjective ranking in [4], it is only an alternative and it does indeed show great advantage for being much easier and faster to conduct. Therefore, it can be utilized to classify any OH around the world without realize subjective rank-ordering method applying questionnaires to conductors.

In future, the evaluation of the optimum weights $(Step3)$ and what are the most appropriate preference functions $(P_j(a,b))$ and its parameters in the implementation of the Promethee II method will be part of another paper.

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