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Application of hybrid Shannon's entropy – PROMEHTEE methods in weighing and prioritizing industrial noise control measures

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ABSTRACT

There are various strategies to prevent and control of noise exposure in occupational settings. This study was aimed to use Shannon's entropy – PROMEHTEE hybrid model for weighing and prioritizing noise control solutions in an oil refinery. At first, the sound pressure levels were measured based on the recommended standard of ISO 9612. Next, criteria and noise control strategies were determined using the Delphi technique. In the third stage, the weights of the criteria were computed using Shannon's entropy method and in the last stage, the solutions were prioritized by the PROMEHTEE method. Based on the results of Shannon's entropy method, criteria in the order of priority included executive cost (0.2710), noise reduction efficiency (0.2531), feasibility (0.2435), safety (0.1120), possible interference with other processes (0.1107) and up-to-datedness of the methods (0.091). Also, based on the results of the PROMEHTEE method, the best solutions were construction of acoustic enclosures for people exposed to noise with a weight of 0.5476, and Modification or change of the work process with a weight of −0.6905, respectively. Therefore, the Shannon's entropy – PROMEHTEE hybrid method can be used as a credible scientific tool to select the most appropriate noise control solution in the industries.

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1. Introduction

When defining surrounding sounds, there could be both wanted and unwanted sounds. The former is pleasant like what we perceive in nature and the latter, is named as noise,

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what humans regard as an annoying sound in daily life as well as occupational environments (Leung et al. 2017; Pourabdian et al. 2019). Although the issue of noise is by no means a new phenomenon, in the recent century, with the increasing speed of urbanization and expansion of various industries and heavy machinery, it has drawn the attention of scholars and legislative bodies worldwide (Said et al. 2020; Abbasi et al. 2021). Specifically, noise is considered a common hazard (physical stressor) in a wide range of industries and environments, such as iron and steel, smelting, wood, textile (Monazzam et al. 2011; Moradirad et al. 2019; Monazzam, Abbasi, and Yazdanirad 2019). So far, several studies have been conducted with aim of determining the mean values of exposure level and Sound Pressure Level (SPL) in this industry, and the results confirm that workers are often exposed to noise above the permissible level (Dehghan et al. 2013). To keep the noise emission to an optimum level and also minimize the exposure of workers, employing practicable control measures is crucial (Mousavi, Moradirad et al. 2019). To achieve this purpose, various control solutions including noise control at the source, noise control at the emission path, and noise control at the receiving point are available. In different situations, different measures are prioritized, though in most cases a combination of these techniques is applied to lower SPL below defined standard ranges (Bies, Hansen, and Howard 2017). Selecting the best noise control strategy by occupational safety and health experts is one of the most fundamental steps, considering the importance of noise control to prevent adverse consequences in employees (Riedel et al. 2019). Since it is often costly and time-intensive to test all control solutions, deciding on choosing the best noise control solution receives special importance. In such circumstances, taking advantage of multi-criteria decision models is highly recommended (Naderzadeh et al. 2017). These decision models are divided into two main categories, namely multi-objective models and multi-criteria models. Multi-objective models are utilized in the designing process, whereas multi-criteria models deal with problematic situations where decision-makers want to choose one of the several options that are evaluated with a set of criteria or rank them (Zavadskas and Turskis 2011). There are different methods for multi-criteria decision making such as VIKOR, FAHP, ANP, TOPSIS and Entropy, each of which has its own advantages and disadvantages (Mousavi et al. 2021; Mousavi, Abbasi, et al. 2019).

One of the highly recommended methods for calculating the standard weight is the Entropy method. This method was proposed by Shannon and Weaver in 1974 and requires a criterion-choice matrix (Haddadha, Namazian, and Yakhchali 2017). Entropy represents the amount of uncertainty in a continuous probability distribution. The basic idea of this method is that the more scatter is the values of an index, the more importance is given to that index. Shannon showed that events with a high probability of occurrence provide less information, and, conversely, the lower is the probability of an event to occur, the greater the information is obtained from it. It is a proper way to measure the relative importance of attributes and convey the true value of data to decision-makers. This method calculates the weights related to each criterion based on the scattering of the criteria. The more scattered is the value of one criterion, the more important is that criterion (Hassanpour and Pamucar 2019).

In recent years, the Shannon entropy method has been used in various fields. For example, Mengyu chai introduced a model of qualitative acoustic emission based on this method (Chai, Zhang, and Duan 2018). Ali Haghizedeh applied it to forecast flood-prone areas (Haghizadeh et al. 2017). Fang Liu exploit it to assess fire risk in large-scale commercial buildings (Liu et al. 2017). Moreover, Roxani Karagiannis utilize this technique to determine the relative weights of constructing composite indices (Karagiannis and Karagiannis 2020). Javad Danaei used it to prioritize the Kish airport projects (Danaei 2017). Wencheng Hung applied the combined Enropy-TOPSIS method to evaluate the urban rail transit system (Huang et al. 2018). Mortaza Yazdani introduced the combined Entropy—EDAS method to assess renewable energy resources (Yazdani et al. 2020). Also, Lam Weng Siew appraised the performance of Construction Companies using Entropy-VIKOR (Siew, Fai, and Hoe 2021).

As mentioned, one of the multi-criteria decision-making methods is the PROMETHEE method. This method has been proposed by Jean-PierreBrans et al. to prioritize options. Options in this method are ranked based on practicability and executability. In this method of decision making, the criteria are determined and their weights are calculated. To calculate the standard weight, multi-criteria decision-making methods can be used (Brans and De Smet 2016). Same as the Shannon entropy method, the PROMETHEE technique has been exploited and developed in a variety of fields. Yunna Wu used the TODIM-PROMETHEE hybrid method to select waste-to-energy plant sites (Wu et al. 2018). Ran Liu introduced the TODIM-PROMETHEE model under the linguistic spherical fuzzy environment to assess safety risk (Liu et al. 2021). Additionally, Hu-Chen Liu improved the FMEA Method by PROMETHEE technique for Proactive Healthcare Risk Analysis (Liu 2019). Ivan Peko applied this method to solve the problem of additive manufacturing process selection (Peko, Gjeldum, and Bilić 2018). Also, Uzer Uygun utilized Fuzzy PROMETHEE to select the display products for furniture stores (Uygun et al. 2018). The literature review showed that the Shannon entropy and PROMETHEE method to solve the problems, select the items, and prioritize the alternatives are widely used in various sciences, such as occupational safety and health and ergonomics. So far, few studies have been conducted on prioritizing noise control strategies in oil refineries, particularly in Iran. The present study was aimed to use the combined Shannon's entropy method and the Preference ranking organization method for enrichment evaluation (PROMETHEE) for selecting the most appropriate noise control solutions.

2. Materials and methods

2.1. Study area

The present study was carried out in Abadan Oil Refinery located in Khuzestan province (south of Iran). The refinery consists of various operating units and provides a variety of products such as gasoline, jet fuel, and diesel. One of the important units of this refinery is the catalytic conversion unit. In this unit, heavy crude gasoline from distillation units is first refined in contact with the catalyst at the appropriate pressure and temperature and then converted to platformite by a platinum-rhenium catalyst. In this unit, 35 permanent workers were employed.

2.2. Method

This descriptive-analytical present study was conducted in four stages in 2019. The steps of study included:

2.3. Measuring noise and determining noise sources

In this step, to identify the sources of noise generation and determine the number of stations with SPLs above dB 85 requiring control solutions, the areas of studied units were divided into squares (5 × 5 meters) and the center of each house was considered as the measuring point, based on the ISO9612 standard and the regular network measurement model. Each measurement was repeated three times with a minimum intervals of 15 seconds, and the mean value was ultimately recorded as the sound level at the station. Measurements were performed using sound level meter (DBAir GA141SO model) and calibrated via the calibrator (model GA607-CASTEL) in one-third of the octave band at the frequencies of 63 to 8000 Hz.

2.4. Determining criteria and solutions for noise control using fuzzy Delphi method

By reviewing the literature and interviewing academics and industrial experts, ten basic effective criteria were considered for choosing the proper noise control solutions. Then, using the fuzzy Delphi method, the opinions of experts on the specified criteria were collected to choose the final effective criteria. For this reason, an anonymous questionnaire was sent to 25 experts and they were asked to specify the relevance of the initial criteria identified with the main research topic and evaluate the importance of each factor using the linguistic terms, as shown in Table 1.

To obtain the opinions of experts, the mathematical relations based on fuzzy numbers were used. It is assumed that the linguistic terms of criterion j from the viewpoint of expert is number i among n experts. In Wij = (aij, bij, cij), the value of j is equal to j = 1, 2,3,… m and the value of i is equal to i = 1,2,3,… m. Thus, the fuzzy value of the criterion j is calculated from the following equation, which is equal to Wj = (aj, bj, cj).

$$\mathrm{aj} = \min \{\mathrm{aij}\} \qquad \text{Equation (1)}$$

$$\mathrm{bj} = \frac{1}{n}\sum_{i=1}^{n} bj \qquad \text{Equation (2)}$$

$$\mathrm{cj} = \max\{\mathrm{bij}\} \qquad \text{Equation (3)}$$

The following relationship was then used to defuzzification.

$$\mathrm{Sj} = \frac{aj + bj + cj}{3} \;\; \mathrm{i} = 1, 2, 3, \ldots \mathrm{m} \qquad \text{Equation (4)}$$

Table 1. Linguistic terms and score of their importance.

Linguistic phrase	Score the importance spectrum
Very low	**1**
Low	**2**
Medium	**3**
much	**4**
Too much	**5**

In this study, based on the opinions of experts, the criteria whose defuzzied value is more than the average value of the spectrum were studied as the criterion with the importance and criteria with defuzzied value less than the average value of the spectrum were considered as less important criteria and were excluded. The terms of consensus or agreement of the experts were fulfilled when 70% of the experts gave the same answer to one of the options for each criterion (Huang, Koopialipoor, and Armaghani 2020; Mousavi et al. 2021).

2.5. Calculating the weight of criteria using Shannon's entropy method

Shannon's entropy method is started with the formation of a decision matrix and pairwise comparisons between the criteria and is calculated by dividing the value of each column of the decision matrix by the sum of the columns of the normalized value of pij. The entropy value of Ej was calculated using Equation (1).

$$E_j = -k\sum_{i=1}^{m} P_{i,j} \times Ln\ Pij\, i = 1,2,3,\ldots,m \qquad \text{Equation (1)}$$

Where K is a constant value that holds the value of Ej between 0 and 1 and P (x) is the probability distribution of the random variable x. Next, the degree of deviation of the dj was calculated, which indicates the amount of useful information on the criterion that is provided to the decision-maker.

$$dj = 1 - Ej \qquad \text{Equation (2)}$$

Finally, the final weight of the Wj criterion was calculated using Equation 3 (Hasnain et al. 2020; Del and Tabrizi 2020).

$$Wj = \frac{dj}{\Sigma dj} \qquad \text{Equation (3)}$$

After determining weights of the criteria by Shannon's entropy method, PROMEHTEEmethod was used to select the most appropriate noise control solution from the available measures.

2.6. Weighing and prioritizing noise control solutions using the PROMEHTEE method

In the first step of the PROMEHTEE method, the criterion-option decision matrix was formed and in the second step, pairwise comparisons of experts were performed based on the preference function. The preference function converts the difference between the two solutions A1 and A2 in a certain criterion to a degree of preference which varies from 0 to 1. There are six types of predefined functions, including functions, ordinary standard criterion, Gaussian criterion, linear criterion, level criterion, linear preference criterion, and indifference zone and segmentation criterion. In this study, normal criteria were used. In the next step, the total preference coefficient was calculated using Equation 4.

$$\pi(A1, A2) = \sum_{j=1}^{n} Pj(A1, A2) \times wj \qquad \text{Equation (4)}$$

Where π (A1, A2) is the weighted sum of P (A1, A2) for each criterion and wj is the weight associated with j, and j is a safe criterion. Then, using the equation of 5 positive currents and using the equation of 6 negative currents, the preference was calculated.

$$\Phi^{+}(A1) = \frac{1}{m-1}\sum\nolimits_{x\varepsilon A}\pi(\acute{A}, X) \qquad \text{Equation (5)}$$

$$\Phi^{-}(A1) = \frac{1}{m-1}\sum\nolimits_{x\varepsilon A}\pi(\acute{X}, A) \qquad \text{Equation (6)}$$

The final ranking was based on the calculation of net flow, which was computed by Equation 7 (Makan and Fadili 2020; Abdullah, Chan, and Afshari 2019).

$$(A1) = \Phi^{+}(A1) - \Phi^{-}(A1) \qquad \text{Equation (7)}$$

2.7. Data analysis

After receiving the questionnaires completed by the experts, all calculations related to the entropy method were performed using MATLAB software and computations related to the PROMEHTEE method and solutions were ranked using Visual PROMETHEE Academic software.

3. Result

3.1. Noise measurement

The results of the sound analysis in the catalytic conversion unit showed that the average value of SPL was equal to 89 dB and the maximum and minimum values of measured SPL were equal to 102 dB and 78 dB. Sixty-five stations were considered as blind spots and also 15 stations had an average value of sound pressure level less than 65 dB. Steam leakage, noise from pump activity, and noise from furnaces were also identified as the main sources of noise.

3.2. Fuzzy Delphi method

The results of the fuzzy Delphi method indicated that the six criteria, as shown in Table 2, were effective criteria in selecting a sound control solution. The two criteria of C2 and C4 were negative in nature, which means that lower values were considered more desirable.

Table 2. The identified criteria for selecting noise control solutions through fuzzy Delphi method.

Criteria	Representing symbol	Nature of criteria
Noise reduction efficiency	C1	Positive
Executive cost or cost-effectiveness	C2	Negative
Feasibility	C3	Positive
Possible interference with other Processes	C4	Negative
Safety	C5	Positive
Up-to-datedness	C6	Positive

Based on the results obtained from the opinions of experts using the fuzzy Delphi method, eight noise control solutions were selected as available options. In order for a solution to be accepted as an alternative, it should meet at least 70% of the experts' agreement. Table 3 reports the results of the integration of experts' opinions using the fuzzy Delphi .

3.3. Shannon's entropy

Executive cost or cost-effectiveness of the method, which was determined using the Shannon entropy weighting method, with a final weight of 0.2796, was found to be the most important criterion in choosing a noise control solution among the criteria (Table 4).

The weight of the criteria obtained by Shannon entropy method was employed to calculate the final weight of the solutions using PROMEHTEE method.

3.4. Promethee method

The final prioritization of noise control solutions using the PROMETHEE method showed that solution 7 with a final weight of 0.5476 was the first priority among the eight options available. Table 5 represents the prioritization of other solutions.

Finally, for a more comprehensive view of the present decision problem, the GAIA diagram, as shown in Figure 1, was used. Based on the results, solution 7 had the highest average proximity to the criteria in the present study.

4. Discussion

The aim of this study was to present a decision-making model for selecting the most suitable Noise control solution by combined Shannon's entropy and PROMETHEE methods in the catalytic conversion unit of an oil refinery. Noise measurement was performed to identify the noise generation sources and determine the noise emission status in the intended unit. To recognize the criteria and strategies of noise control, with reviewing literature and conducting expert interviews, the Fuzzy Delphi method was used as a guide tool for selecting the criteria and strategies of noise control. The results of Shannon's entropy method, which is a combined opinion of experts on the criterion, indicated that the criterion of the efficiency with a final weight of 0.2796 received the most importance and the criterion of non-interference in the process with a final weight of 0.1107 was the least important among the criteria. In a study carried out by Zare and Shirali, it was found that there is a direct linear relationship between efficiency and cost, and cost also enhances with increasing efficiency. In this study, the criterion of efficiency with a final weight of 0.2710 and cost with a final weight of 0.2531, as two the criteria with relative weight, are higher than other criteria, indicating the importance of these two criteria in choosing the noise control solution. Ghotbi Ravandi et al. used the AHP-TOPSIS model to prioritize the criteria for selecting a noise control solution in a tire manufacturing company located in Fars province of Iran. The results showed that cost and implementation of the method (final weight 0.481) is the most important criterion for selecting a control solution

Table 3. Results of integration of experts' opinions on sound control solutions using fuzzy Delphi method.

Representing symbol	Alternatives	Spectrum of importance					Fuzzy value aggregation			defuzzified value	Percentage of consensus
		Very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)	L	M	U		
Alt1	Use of hearing protection devices (PPEs)	–	–	–	22	3	4	4.12	5	4.31	0.88
Alt2	Control of exposure time	–	–	4	18	3	4	3.96	5	4.23	0.72
Alt3	Replacement of decrepit devices	–	3	4	18	2	2	4	4	3.50	0.72
Alt4	Repair and replacement of defective parts of devices	–	–	3	19	3	3	3.24	4	3.37	0.76
Alt5	Construction of acoustic enclosures on loud sources	–	–	–	23	2	4	4.08	5	4.29	0.92
Alt6	Installation of silencers on the air jets	–	–	3	19	3	3	3.24	4	3.37	0.76
Alt7	Construction of acoustic enclosures for people exposed to noise	–	–	3	20	3	3	3.36	5	3.68	0.80
Alt8	Modification or change of the work process to reduce the steam release	–	–	–	23	2	4	4.08	5	4.29	0.92

Table 4. Weights of criteria for selecting a noise control solution using Shannon entropy method.

Criteria	Representing symbol	Weight
Feasibility	C1	0.2435
Executive cost or cost-effectiveness	C2	0.2710
Safety	C2	0.1120
Possible interference with other processes	C2	0.1107
Noise reduction efficiency	C4	0.2531
Up-to-datedness	C5	0.091

Table 5. Final prioritization of noise control solutions based on the results of the PROMETHEE method.

Noise control solutions	Phi	Phi+	Phi-	prioritization
Alt7	0.5476	0.6429	0.0952	**1**
Alt2	0.4286	0.5714	0.1429	**2**
Alt1	0.2619	0.5476	0.2857	**3**
Alt5	0.0238	0.3571	0.3333	**4**
Alt3	−0.0238	0.3571	0.3810	**5**
Alt6	−0.0238	0.3333	0.3571	**6**
Alt4	−0.5238	0.1905	0.7143	**7**
Alt8	−0.6905	0.0952	0.7857	**8**

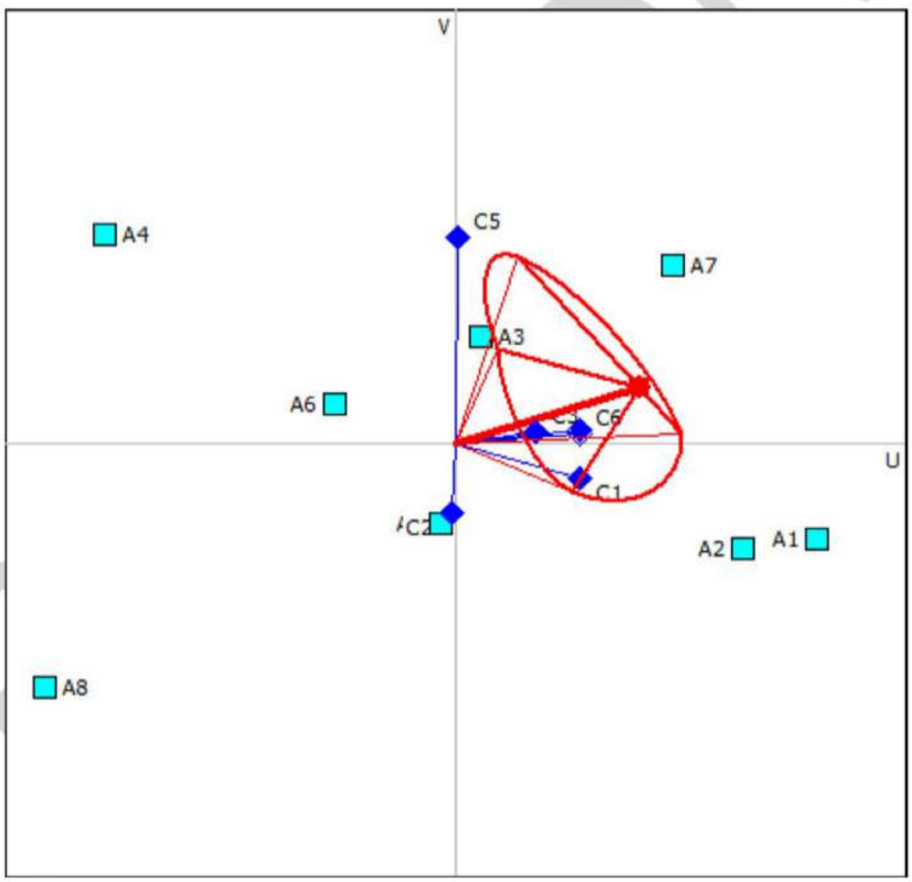

Figure 1. Subjective model of human mind decision-making based on GAIA chart.

(Ghotbi-Ravandi et al. 2020). Ishaqi also applied the AHP method to weigh the criteria for choosing a noise control solution in a glass company located in Hamadan province of Iran. The results of the AHP method illustrated that the criterion of feasibility had the highest relative weight or in other words, the greatest importance, and the cost criterion also had the lowest relative weight or in other words, the least importance among the studied criteria (Mahboobe, Golmohamadi, and Riahi-Korram 2012). In another study conducted by Sakhvati in the cement industry, the criterion of initial investment cost was determined as the most important criterion for opting the noise control method (Sekhavati et al. 2014). The reasons of these differences can be due to the different industries studied and also the different methods of calculating the weight of the criteria and can also be associated with the different teams of experts in the study. In all three studies of Ravandi, Sakhvati, and Ishaqi, the hierarchical analysis method was used, but in the present study, Shannon's entropy method was exploited to compute the weight of the criteria. Performing long and complex calculations in the hierarchical analysis method can be considered as one of the disadvantages of this technique, while Shannon's entropy method uses fewer relationships and calculations to estimate the weight of the criteria. The results of PROMEHTEE method showed that the use of noise chamber with the weight $\Phi = 0.5476$ was the best and the first choice of the solution among the existing items, and the solution of modification or change of the work process to reduce the amount of steam output with the weight $\Phi = 0.\text{-}69$ was the last choice. In study performed by Nasiri et al., it was suggested that the enclosure of noise-generating sources can significantly reduce the pressure level, however, the limitations of this method should also be taken into account (Nassiri, Zare, and Golbabaei 2007). Golmohammadi et al. concluded that building a noise chamber on noise-generating sources can decrease noise exposure (Monazzam et al. 2011). In this study, it was found that this method is one of the most effective solutions for noise control in the catalytic conversion unit. Furthermore, the construction of noise chambers for exposed workers was identified as the first priority of decision-makers. Therefore, in the opinion of the decision-makers, the construction of a noise chamber for exposed workers takes precedence over the construction of enclosures on noise-generating sources. Solutions such as repairing worn-out devices, replacing old devices, and changing the process due to high costs were given the last priorities by decision-makers, which highlights the high weight of final cost in choosing the method of noise control in the industry. Similarly, the results of Shannon's entropy method showed that the weight of efficiency and cost is higher than other criteria in choosing a noise control solution and these two criteria played a more important role.

5. Conclusion

Based on the findings, the criterion of executive cost and cost-effectiveness was appeared to be the most important criteria for choosing a noise control solution. The best solution also was the construction of a noise chamber. The Structured Preferential Ranking Method for Enriching Evaluations (PROMEHTEE) is an effective tool in the multi-criteria decision-making process, which can be used when decision-makers are unable to accurately prioritize options due to inability or lack of knowledge. Moreover, This study indicated that the structured preferential ranking method for enriching evaluations can be applied as a scientific tool to select the most appropriate noise control solution in the oil industry and other industries in which a choice of noise control is felt as a need. One of the advantages of this method is the use of Visual PROMETHEE Academic software in performing calculations related to it, which can facilitate the computation process and provide experts with sufficient data for a better decision-making process by having various outputs. The inability of this method to estimate the weight of the criteria can be regarded as a shortcoming, however, other multi-criteria decision methods such as Shannon's entropy method can be employed to overcome this problem.

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Ethical issues

The study protocols were approved by the Ethics Committee of Behbahan University of Medical Sciences, Behbahan, Iran (Ethical code: IR.BEH.REC.1397.021).

Disclosure statement

No potential conflict of interest was reported by the authors.

Authors' contributions

All authors contributed and were involved in the problem suggestion, experiments design, data collection, and manuscript approval. Q2

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