ISSN 1816-6075 (Print), 1818-0523 (Online)
Journal of System and Management Sciences
Vol. 14 (2024) No. 3, pp. 177-188
DOI:10.33168/JSMS.2024.0311

Multi-Criteria Decision Making with Analytical Hierarchy Process for Headphone Recommender System

Muhammad Rizal, Arya Wicaksana*

Department of Informatics, Universitas Multimedia Nusantara, Tangerang 15810, Indonesia
arya.wicaksana@umn.ac.id (Corresponding Author)

Abstract. The increasing global market for consumer headphones grows the complexity of selecting the right pair suited to individual preferences due to the wide variety of models and manufacturers. This study uses the Analytical Hierarchy Process (AHP) method to create a web-based headphone recommender system to solve this problem. The algorithm considers user-specific criteria for recommending headphones: sound quality, comfort, weight, pricing, functionality, and phone call ability. Pairwise comparisons are used to build the decision hierarchy and criteria weights for the AHP to calculate user-specific headphone recommendations. The usefulness, satisfaction, ease of use, and ease of learning of the system are evaluated using the USE questionnaire with 38 respondents. The questionnaire results produce an average score of 79%. The recommender system exemplifies the possibilities of using AHP to provide user-specific recommendations for Multi-Criteria Decision Making (MCDM) problems like the headphone recommender system.

Keywords: AHP, headphone, MCDM, recommender system, USE questionnaire

1. Introduction

The global headphones market is expected to grow to 1.3 billion pieces in 2028, with forecasted growth of 15.6% from 2023 to 2028 (Statista, 2023), and the revenue in 2023 amounts to US$ 18 billion worldwide. Ten major brands dominate 51% of the market (*Headphones - Worldwide*, 2023). Apple leads the headphone market with 12% shares worldwide, with Sony (8%), JBL (7%), Bose (6%), Samsung (4%), Xbox (4%), Razer (3%), Sennheiser (3%), and various other brands totaling at 49%. Headphones can be divided into four categories based on shape and size: over-ear, on-ear, earbuds, and in-ear (Henney, 2016). It can also include extra features, e.g., wireless and noise canceling (McCuaig, 2023a, 2023b). The number of headphone brands in the market keeps on expanding. At least 17 headphone brands exist in the U.S. as of March 2023 (Kunst, 2023) and 31 globally (Ferjan, 2023). The wide variety of headphones types and characteristics available in the market introduces difficulty for users to select the most suitable one based on their preferences.

Recommender systems have been developed recently to address the difficulty, with an example of movie recommender systems (Behera & Nain, 2023; Salmani & Kulkarni, 2021). The many genres and number of movies available worldwide require viewers to put effort into recognizing similar movies to the ones they have watched and liked, and selecting the most suitable or preferred headphone shares the exact problem nature of Multi-Criteria Decision Making (MCDM), which aims to determine the best alternative with multiple criteria (Taherdoost & Madanchian, 2023). Using Analytical Hierarchy Process (AHP) for recommender systems with MCDM improves accuracy (Wongvilaisakul et al., 2023). Thomas (Saaty, 2002) created the Analytical Hierarchy Process (AHP), a decision-making approach to help prioritize and evaluate alternatives based on the decision-makers preferences. Thus, AHP is well-suited for recommendation scenarios since it is designed to capture and model the subjective judgments of decision-makers (Russo & Camanho, 2015), in addition to the usability and logical process for arriving at recommendations (Canco et al., 2021).

The main objective of this study is to develop a web-based recommender system for headphones. The development involves designing and implementing the recommendation system, including testing and evaluating the results using actual data retrieved from rtings.com. The recommender system aims to provide decision support for the headphone's Multi-Criteria Decision Making (MCDM) problem. The proposed method for solving the MCDM problem in this study is AHP. There are no known related works on headphone recommender systems with AHP. The proliferation of headphone brands and sky-rocketing consumption drive the need to address the MCDM efficiently and effectively. The USE questionnaire in this study evaluates the usefulness, satisfaction, ease of use, and ease of learning of the headphone recommender system with AHP. The innovation lies in the simplicity and straightforwardness of the developed system using AHP without requiring any filtering methods commonly deployed for recommender systems that introduce the cold start problem.

The remainder of the paper is structured as follows. Section 2 describes the preliminaries, and Section 3 presents the research methodology. Section 4 discusses the results. Finally, Section 5 concludes the paper with some recommendations.

2. Preliminaries

2.1. Related Works

(Prasetyaningrum et al., 2020) combines AHP and sentiment analysis for recommendation systems to obtain the best alternative recommendations based on people's criteria. The system can suggest to users based on their criteria, available options, and consensus. (Yumoto, 2018) uses the AHP to develop a product recommendation system with additional methods: normalization allocation and Hough conversion.

(Wongvilaisakul et al., 2023) solves the Multi-Criteria Decision Making (MCDM) on the graduate admission recommender system using AHP and fuzzy AHP. The fuzzy AHP demonstrates higher accuracy compared to the AHP, although not significant. Various works on the use of AHP for recommender systems and MCDM signify the importance of the method in addressing the problem (Dhammayanti et al., 2019; Lamaakchaoui et al., 2018; Nguyen et al., 2011) in addition to (Leonardo et al., 2019) other domain such as expert system.

The results of this previous work confirm the practicality, accuracy, and usage of AHP in addressing MCDM for recommender systems. Moreover, the hardware requirements for the recommender systems using AHP are lesser than other methods like filtering. Filtering approaches commonly deployed in recommender systems require immense system set up to address the cold start problem. With its adequate performance, the simplicity and practicality of AHP make it suitable for MCDM and recommender systems. At the time of this paper's writing, no know publications exist on the headphone recommender system, not to mention the use of AHP for the application. The development of the headphone recommender system in this study not only aims to address the MCDM issue in choosing a user-preferred headphone but also to reveal the usefulness, satisfaction, ease of use, and ease of learning of the system.

2.2. Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) is a decision-making technique that helps prioritize and evaluate alternatives systematically. Thomas L. Saaty developed it in the 1970s. AHP is particularly useful when dealing with complex, multi-criteria decision problems. The following are the details of the AHP process (Dhammayanti et al., 2019; Saaty, 2002):

- **Define the decision problem:** Clearly define the decision problem to be addressed. Identify the criteria (factors) relevant to your decision and the alternatives (options) you need to evaluate.
- **Create a decision hierarchy:** Construct a hierarchical structure that organizes the criteria and alternatives in a tree-like format. The hierarchy consists of three levels: (1) target, (2) criteria, and (3) alternatives.
- **Pairwise comparisons:** For each pair of elements in the hierarchy, conduct pairwise comparisons. This involves comparing the importance or preference of one element over the other. Use a scale from 1 to 9 to express the relative importance of one element over another. The importance of element i relative to element j is denoted as A(i/j), where A represents the pairwise comparison matrix.
- **Create the pairwise comparison matrix:** Construct a square matrix A with elements A(i/j) representing the pairwise comparison values, i.e., for a decision with n elements, the pairwise comparison matrix A will have elements A(i/j) for i, j = 1, 2, ..., n.
- **Normalize the pairwise comparison matrices:** Normalize each matrix A by calculating the geometric mean of each row. Denote the normalized matrix as A'.
- **Calculate priority weights:** Calculate the priority weights for each level using the normalized matrices A'. For the criteria level, let w_c(i) represent the priority weight of criterion i, and for the alternative level, let w_a(i) represent the priority weight of alternative i.
- **Check for consistency:** Calculate the Consistency Index (CI) and the Consistency Ratio (CR) to check the consistency of the judgments made during the pairwise comparisons. The Random Index (RI) values for different matrix sizes are pre-calculated and can be found in AHP tables or online. The followings are the formula to calculate CI and CR.

$$CI = \frac{\lambda \max - n}{n-1} \quad \mathrm{CI} = \frac{(\lambda\mathrm{max\text{-}n})}{\mathrm{n\text{-}1}} \ (1)$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \ (2)$$

- **Compute the overall rankings:** Multiply the priority weights of each criterion by the priority weights of the alternatives under that criterion and sum the results for each alternative to get the overall ranking of the alternatives. The overall ranking of alternative i = w_c(criterion_1) * w_a(i) + w_c(criterion_2) * w_a(i) + … + w_c(criterion_n) * w_a(i).

2.3. USE Questionnaire

Usefulness, satisfaction, and ease of use are USE's three usability measuring components. Several observations also revealed a relationship between usability criteria and simplicity of use. A rise in usefulness will be followed by a rise in the criterion of ease of use and vice versa. These two factors will have a significant impact on satisfaction. Two categories of factors affect the ease of use parameter: ease of learning and ease of usage (Lund, 2001). The usefulness factor is usually less critical when using the system is mandatory. For internal systems, issues affecting the criterion for ease of use may be separated into two categories: ease of use and ease of learning. The following is the full version of the USE questionnaire package (Faria et al., 2016).

USEFULNESS:

1. It helps me be more effective.
2. This helps me be more productive.
3. It is useful.
4. It gives me more control over activities in my life.
5. It makes the things I want to accomplish easier to get done.
6. It saves me time when using it.
7. It meets my needs.
8. It does everything I would expect it to do.

EASE OF USE:

9. It is easy to use.
10. It is simple to use.
11. It is user friendly.
12. It takes the fewest steps possible to accomplish what I want to do with it.
13. It is flexible.
14. I can use it without written instructions.
15. I don't notice any inconsistencies as I use it.
16. Both occasional and regular users would like it.
17. I can recover from mistakes quickly and easily.
18. I can use it successfully every time.

EASE OF LEARNING:

19. I learned to use it quickly.
20. I can easily remember how to use it.
21. It is easy to learn to use it.
22. I quickly became skillful with it.

SATISFACTION:

23. I am satisfied with it.
24. I would recommend it to a friend.
25. It is fun to use.
26. It works the way I want it to work.
27. It is wonderful

28. I feel I need to have it.
29. It is pleasant to use.

3. Methods

The required headphone data for this study is collected from rtings.com and official headphone brand websites. There are 410 headphone data gathered to develop the headphone recommender system with more than 50 brands. Each headphone record has to have information on its sound quality, comfort, weight, pricing, functionality, and phone call ability. Subjective evaluation in attributes such as sound quality and comfort are retrieved from rtings.com, which reviews and compares numerous headphones with sound methodology. In cases where there is no evaluation yet on rtings.com for particular headphones, the authors provide the score for the attributes. This is only for the implementation and testing purposes of this study. After the system is deployed, the administrator handles this task directly on the database.

The design of the headphone recommender system in this study includes a data flow diagram (DFD), flowchart, and prototypes of the graphical user interface (GUI). The system is named Audio Arena, and headphone data are retrieved from external sources like rtings.com. An administrator can also insert new headphone data into the database directly. Headphone data include name, brand, release date, sound quality, weight, comfort, phone call ability, and image. The images of the headphones are stored in the filesystem, and the pathname is saved in the database. Figures 1 and 2 illustrate the information flow of the headphone recommender system.

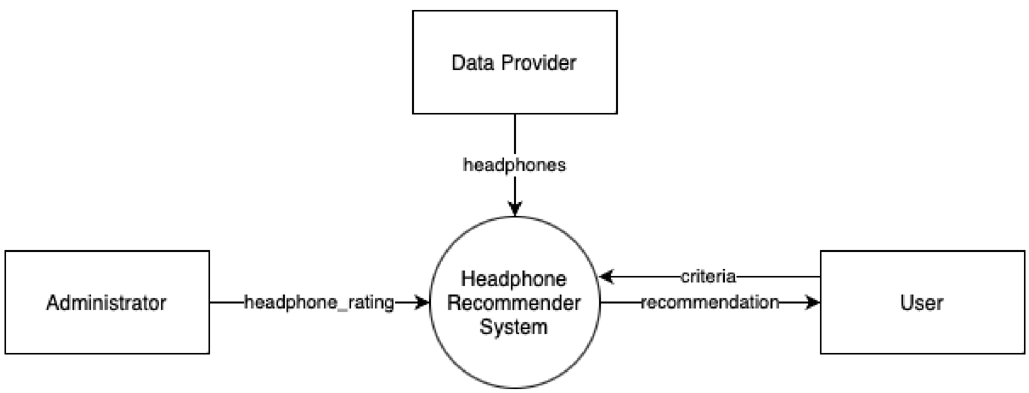

Fig. 1: Headphone recommender system context diagram.

There are three processes within the headphone recommender system (Audio Arena) as detailed in the Level 1 data flow diagram in Figure 2: fetch headphone data, rate headphones, and get a recommendation (AHP). The administrator uses the fetch headphone data to collect new headphone data from the external provider. The data providers' information is preset in the system, and the administrator can manually configure this setting. Scoring for unavailable attributes from the external data provider uses the Rate Headphone function. The end users use the Get Recommendation function to obtain headphone recommendations based on the AHP. The Get Recommendation flowchart is shown in Fig. 3.

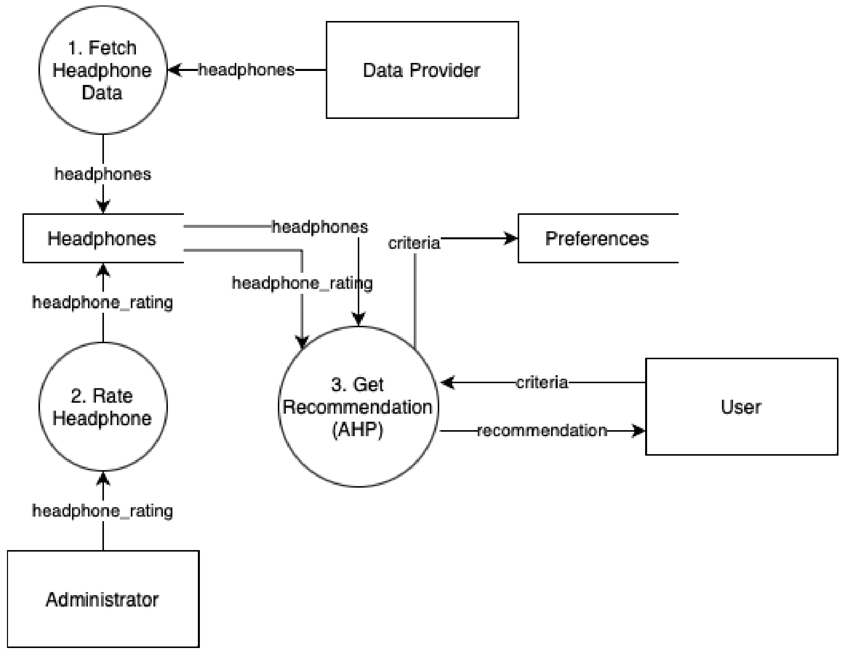

Fig. 2: Level 1 data flow diagram.

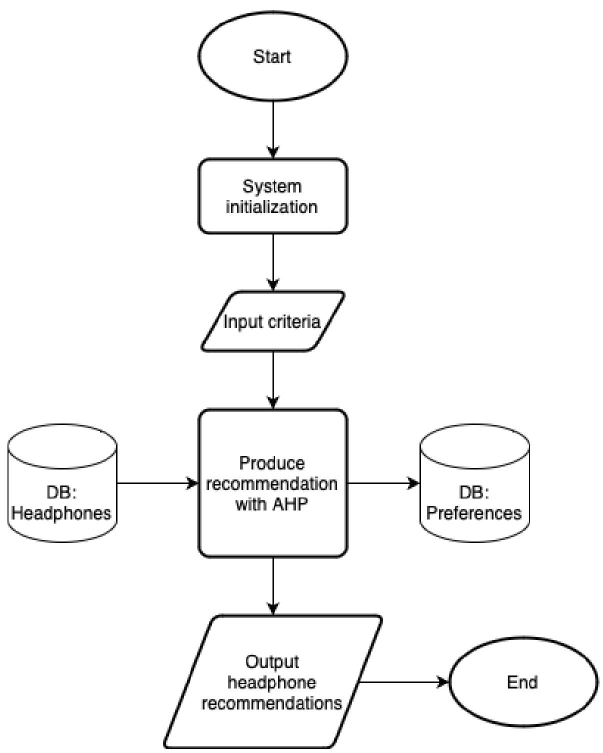

Fig. 3: Get recommendation (AHP) flowchart.

The main flowchart of Audio Arena starts with the user providing the system with the weight for each criterion: functionalities, sound quality, comfort, weight, price, and phone call ability. The calculations using the Analytical Hierarchy Process (AHP) determine the results of headphone recommendations that match the weight of the user's criteria. The structure of the AHP for the headphone recommender system is shown in Fig. 4.

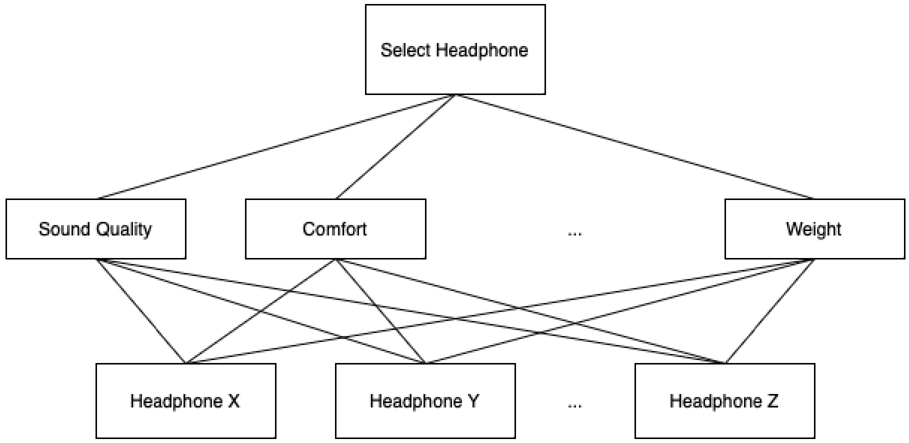

Fig. 4: Hierarchy structures of AHP for headphone recommender system.

AHP's hierarchical structure was developed to allow for the methodical and impartial evaluation of alternatives and criteria. The purpose, criteria, and options comprise the three tiers of the AHP's hierarchical structure. The overall goal of the decision-making process is the aim. The alternatives are the accessible solutions for reaching the purpose, while the criteria are important considerations. The criteria and alternatives follow the purpose. A pairwise comparison matrix is used to analyze each hierarchy level. The pairwise comparison matrix contrasts each element's relative importance on the same scale. Due to each member's equal importance, the matrix's diagonal elements are set to one. The off-diagonal components show how significant a particular component is concerning other components. The relative relevance of the various components is assessed using a scale of values. After the pairwise comparison matrix is complete, the relative weights of the criteria and alternatives are determined using the eigenvector approach.

Figure 5 displays the prototype of the recommendation results web page. On this page, the users have to input the criterion and importance level for the criterion. Users can add more criteria to the system: sound quality, comfort, weight, pricing, functionality, and phone call ability. The headphone recommendation page shows the produced calculation based on AHP for the criteria and level of importance set by the user. The page displays the top three headphones according to the AHP score calculation.

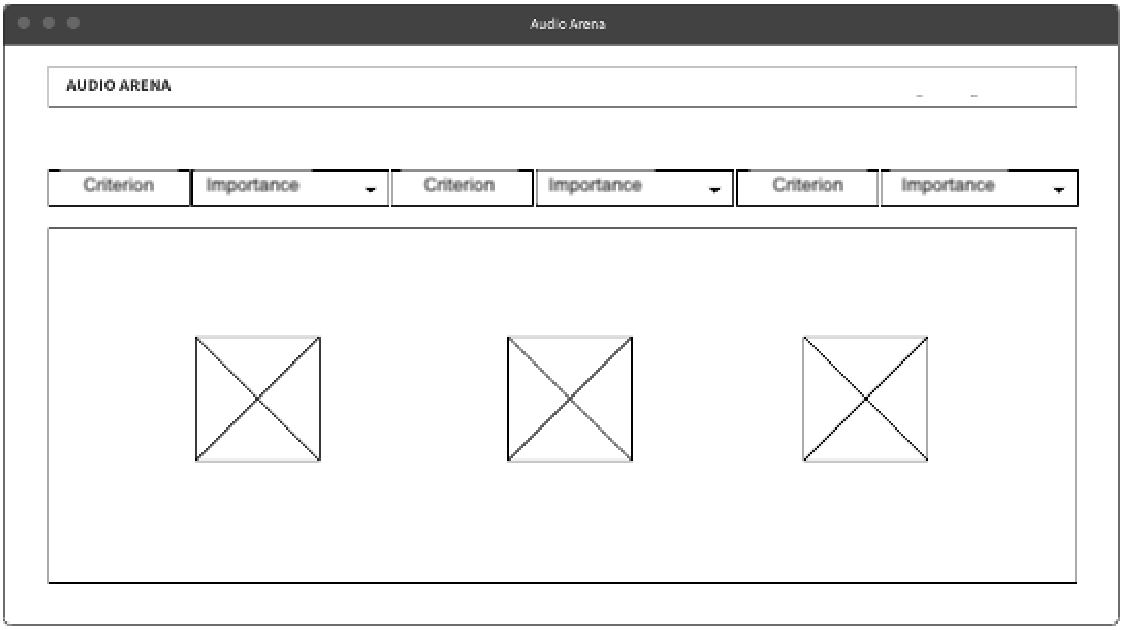

Fig. 5: Headphone recommendation page prototype.

White-box testing is conducted to validate the recommendation system design and implementation. In addition to AHP testing, weights criteria range from one to nine: 1-equal importance, 3-moderate importance, 5-strong importance, 7-very strong importance, and 9-extreme importance (2,4,6,8 values in-between). In the AHP test scenario, the criteria are set for the parameters in Table 1. The test aims explicitly to verify and validate the AHP implementation for the recommender system.

Table 1: Criteria and level of importance

Criteria	Importance
Functionalities	1-equal
Sound quality	9-extreme
Comfort	7-very strong
Weight	5-strong
Price	5-strong
Phone call ability	5-strong

4. Results and Discussion

The implementation of the design of the recommendation system uses the web programming language (HTML and PHP) and MySQL database. Figure 6 is a view of the home page. There are three main menus, Home, About Us, and Contact Us. Home menu to return to the homepage, the about us menu to go to the Our Team page, and the last contact us menu to the Contact page. Figure 7 displays the best headphone recommendations on the main page at the bottom. The recommendation page features three of the best headphones out on the web.

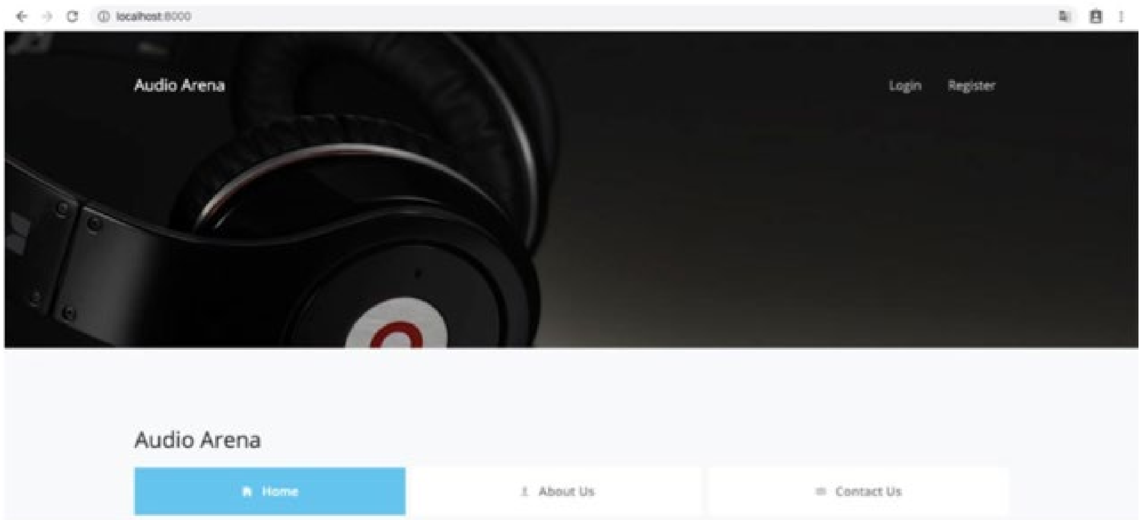

Fig. 6: Headphone recommender system homepage.

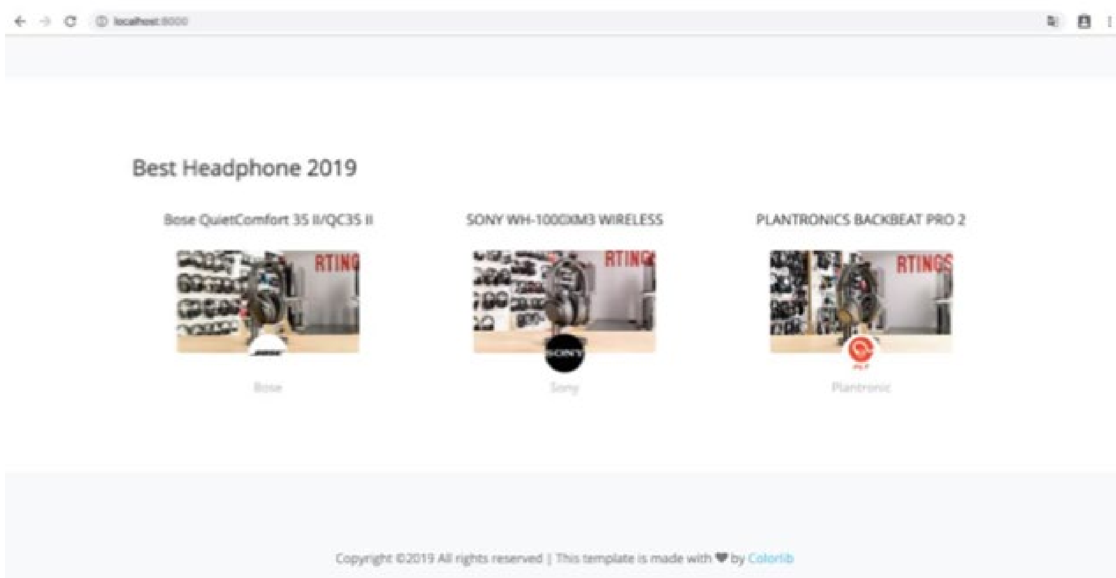

Fig. 7: Headphone recommendation page.

The produced recommendation shown in Fig. 7 conforms with the AHP calculation for the given test scenario in Table 1. The pairwise comparison matrix and normalization matrix for the AHP testing is given in Tables 2 and 3—the manual calculations for the AHP match with the results produced by the recommender system. The limitation found in this study is the availability of external data sources that can provide headphone data for the system to keep it up to date. Moreover, the programming interface allows easy access to the headphone data provided by external sources. Although with AHP, the system can produce a recommendation for headphones based on the user's criteria and level of importance, the method lacks qualitative processing capability for qualitative criteria. This limits the usefulness of the system as qualitative criteria for the headphone have to be evaluated separately before the headphone can be added into the recommender system for AHP calculations.

Table 2: Pairwise comparison matrix

Criteria	Functionalities	Sound Quality	Comfort	Weight	Price	Phone Call Ability
Functionalities	1	1/9	1/7	1/5	1/5	1/5
Sound quality	9	1	1/9	1/5	3	1/9
Comfort	7	9	1	3	1/9	3
Weight	5	5	1/3	1	1/7	1/9
Price	5	1/3	9	7	1	1/7
Phone call ability	5	9	1/3	3	9	1

Table 3: Normalized pairwise comparison matrix

Criteria	Functionalities	Sound Quality	Comfort	Weight	Price	Phone Call Ability
Functionalities	0.03125	0.00454	0.01308	0.01388	0.01486	0.04205
Sound quality	0.28125	0.04090	0.01017	0.01388	0.22298	0.02336
Comfort	0.21875	0.36818	0.91569	0.20833	0.00825	0.63084
Weight	0.15625	0.20454	0.03052	0.69444	0.01061	0.07009
Price	0.15625	0.01363	0.82412	0.48611	0.07432	0.02336
Phone call ability	0.15625	0.36818	0.03052	0.20833	0.66894	0.21028

User satisfaction is evaluated using the USE Questionnaire with a 5-point Likert scale. The questionnaire was distributed to 38 respondents that actively used headphones. The USE Questionnaire results are shown in Table 4, with an overall average of 79.045%. This indicates the acceptance of the headphone recommendation system, with the highest Ease of Learning factor. The practical application of this recommender system is confirmed by the high Ease of Use factor of 80.09%. However, the Usefulness factor can be further improved to reach more than 80% evaluation score on the USE Questionnaire.

Table 4: USE questionnaire results

Parameter	Score	Statement
Usefulness	70.72%	Good
Ease of Use	80.09%	Very Good
Ease of Learning	85%	Very Good
Satisfaction	80.37%	Very Good

The results of this study contribute to the practical development of recommender systems for headphones and other similar domains. The AHP produces and ranks alternatives (headphones) based on the criteria and their importance according to the user. A hierarchy structure is set up for the AHP to determine the best headphone in this study based on the scores of each criterion and the level of importance for the criterion. Although qualitative criteria cannot be calculated directly for the AHP, a simple workaround in this study allows the quantization of the qualitative criteria for the AHP. This workaround can also be applied in other domains where AHP cannot process qualitative criteria.

5. Conclusions

This paper demonstrates the use of AHP in a headphone recommender system. The system is designed, implemented, and tested on the web using HTML, PHP, and MySQL. The headphone recommender system considers functionalities, sound quality, comfort, weight, price, and phone call ability. The USE Questionnaire yields 79% on average from 38 respondents, with the Ease of Learning factor being the highest and the Usefulness factor being the lowest. The limitations of this study are the availability and accessibility of headphone data and the use of additional methodology for evaluating qualitative criteria. Future work on real-time data mining to extract headphone dataset on-the-fly allows the system produces more accurate headphone recommendation. In addition, incorporating sound scoring methods for qualitative criteria enhances the quality of the system recommendations.

Acknowledgement

Universitas Multimedia Nusantara fully supports this work. The authors thank reviewers for the given inputs to enhance the quality of the paper.

References

Behera, G., & Nain, N. (2023). Collaborative Filtering with Temporal Features for Movie Recommendation System. *Procedia Computer Science*, *218*(1366–1373). https://doi.org/https://doi.org/10.1016/j.procs.2023.01.115

Canco, I., Kruja, D., & Iancu, T. (2021). AHP, a Reliable Method for Quality Decision Making: A Case Study in Business. *Sustainability*, *13*(24), 13932. https://doi.org/10.3390/su132413932

Dhammayanti, K., Wicaksana, A., & Hansun, S. (2019). Position Placement Dss Using Profile Matching And Analytical Hierarchy Process. *International Journal of Scientific & Technology Research*, *8*(11). http://www.ijstr.org/paper-references.php?ref=IJSTR-1119-24432

Faria, T. V. M., Pavanelli, M., & Jr., J. L. B. (2016). Evaluating the Usability Using USE Questionnaire: Mindboard System Use Case. In *Lecture Notes in Computer Science* (pp. 518–527). Springer. https://doi.org/10.1007/978-3-319-39483-1_47

Ferjan, M. (2023). *31 Best Headphone Brands (Survey Rankings Revealed)*. https://headphonesaddict.com/best-headphone-brands/

Headphones - Worldwide. (2023). Statista Market Insights. https://www.statista.com/outlook/cmo/consumer-electronics/tv-radio-multimedia/headphones/worldwide

Henney, M. (2016). *Which type of headphones are best for you?* https://www.rtings.com/headphones/learn/over-ear-vs-on-ear-vs-in-ear-vs-earbuds-comparison

Kunst, A. (2023). *Most used headphones by brand in the U.S. as of March 2023*. https://www.statista.com/forecasts/997153/most-used-headphones-by-brand-in-the-us

Lamaakchaoui, C., Azmani, A., & El Jarroudi, M. (2018). The AHP Method for the Evaluation and Selection of Complementary Products. *International Journal of Service Science, Management, Engineering, and Technology*, *9*(3), 106–115. https://doi.org/10.4018/IJSSMET.2018070107

Leonardo, J., Young, J. C., & Hansun, S. (2019). EARLY DETECTION OF PULMONARY TUBERCULOSIS DISEASE WITH FUZZY AHP EXPERT SYSTEM. *COMPUSOFT: An International Journal of Advanced Computer Technology*, *8*(10). https://www.ijact.in/index.php/ijact/article/view/1041

Lund, A. M. (2001). Measuring usability with the USE questionnaire. *Usability Interface*. https://doi.org/10.1177/1078087402250360

McCuaig, V. (2023a). *The 6 Best Noise Cancelling Headphones - Summer 2023*. https://www.rtings.com/headphones/reviews/best/by-feature/active-noise-cancelling

McCuaig, V. (2023b). *The 7 Best Wireless Bluetooth Headphones - Summer 2023*.

Nguyen, H. D., Lo, W.-T., & Sheu, R.-K. (2011). An AHP-Based Recommendation System for Exclusive or Specialty Stores. *2011 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery*, 16–23. https://doi.org/10.1109/CyberC.2011.13

Prasetyaningrum, I., Fathoni, K., & Priyantoro, T. T. J. (2020). Application of recommendation system with AHP method and sentiment analysis. *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, *18*(3), 1343–1353. https://doi.org/10.12928/TELKOMNIKA.v18i3.14778

Russo, R. D. F. S. M., & Camanho, R. (2015). Criteria in AHP: A systematic review of literature. *Procedia Computer Science*. https://doi.org/10.1016/j.procs.2015.07.081

Saaty, T. L. (2002). Decision making with the Analytic Hierarchy Process. *Scientia Iranica*. https://doi.org/10.1504/ijssci.2008.017590

Salmani, S., & Kulkarni, S. (2021). Hybrid Movie Recommendation System Using Machine Learning. *2021 International Conference on Communication Information and Computing Technology (ICCICT)*. https://doi.org/10.1109/ICCICT50803.2021.9510058

Statista. (2023). *Volume of the headphones market worldwide from 2018 to 2028*. https://www.statista.com/forecasts/1284259/sales-volume-headphones-market-worldwide

Taherdoost, H., & Madanchian, M. (2023). Multi-Criteria Decision Making (MCDM) Methods and Concepts. *Encyclopedia*, *3*(1), 77–87. https://doi.org/10.3390/encyclopedia3010006

Wongvilaisakul, W., Netinant, P., & Rukhiran, M. (2023). Dynamic Multi-Criteria Decision Making of Graduate Admission Recommender System: AHP and Fuzzy AHP Approaches. *Sustainability*, *15*(12), 9758. https://doi.org/10.3390/su15129758

Yumoto, M. (2018). Development of Product Recommendation System with AHP according to alternatives' evaluation with Normalization allocation and Hough conversion. *IEEJ Transactions on Electronics, Information and Systems*, *138*(7), 886–898. https://doi.org/10.1541/ieejeiss.138.886