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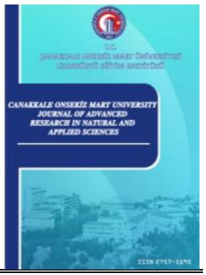

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Effect of Sound Absorption on Noise Reduction in the Automotive Industry

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Abstract − Industrial noise is one of the most common physical factors that cause annoyance and damage to workers' health in the long term. Precautions should be taken to reduce noise and to improve acoustic performance in industrial working environments. This paper aims to analyze the acoustic performance of the automotive industry contributes to the global outcomes of sustainability and develop strategies for improving the quality of the working environment through improvement scenarios. For this purpose, the automotive industry in Türkiye was examined as a case study. In-situ acoustic measurements were made in the seat manufacturing unit of an automotive factory, and the current situation was transferred to the simulation program. The effects of acoustic improvements on A-weighted sound pressure level and reverberation time at mid-frequencies (500, 1000, 2000 Hz) were investigated through three scenarios. In the investigations, noise distributions were carried out through noise mapping. The A-weighted sound pressure levels in the automotive industry were reduced by approximately 15 dB. As a result of the study, suggestions for noise control precautions and their effects on the automotive industry seat manufacturing unit are presented.

Keywords − *Acoustics simulation, automotive industry, industrial noise control, noise reduction, sound absorption*

1. Introduction

Industrial noise has been one of the important physical risk factors for employee health. Noise has physical, physiological, and psychological effects on workers and major effects on worker productivity [1-3]. Noise affects people's nervous system and hearing, weakens workers' concentration, and reduces attention and reaction skills [4-5]. However, the productivity and efficiency of employees, which vary due to noise, have been important factors affecting the overall performance of any organization, from small to large companies [6]. Since the 90s, interest in the relationship between the working environment and productivity has increased, and, in this context, research has focused on employee job satisfaction, and reforms and improvements have been made.

The automotive industry is one of the most developed industries in the world and is the engine of the economy of many states. The automotive industry is characterized by high consumption of raw materials to produce cars, trucks, and buses. Some companies have units with a full production cycle, and several companies only deal with the assembly and production of automobile parts [7, 8]. Employee productivity in the automotive industry needs to be increased by improving health and safety conditions in the workplace. Occupational noise in the automotive industry has been a detailed area evaluated and studied.

Depending on various production processes in the automotive industry, different noise levels occur and the

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noise exposure levels of employees vary. However, it has been determined that indoor noise levels are high according to the regulations of the relevant countries in the measurements made in automotive factories [9-14]. A hierarchy of noise control steps should be followed in controlling production area noise in factories. Within the scheme, precautions should be taken and implemented from the highest to the lowest impact (Figure 1). In the hierarchy of noise control, it is generally necessary to take various precautions at the source, transmission path, and receiver [15-17]. The most effective and expected noise control is achieved through engineering control precautions at the source and the transmission path. Different approaches to engineering control methods exist in factories [18, 19]. Variables such as industrial sector, production process, machine and human interactions, and plant characteristics effectively determine the noise control precautions that can be taken. Simultaneously, the noise control precautions should be compatible with other working conditions and not harm the production process. For this reason, using absorptive materials, noise barriers, and enclosures creates effective engineering noise control precautions in industrial plants [20-22]. Moreover, noise control by absorption and enclosure of the source are effective noise control mechanisms in the transmission path. Research on noise control in automotive factories is quite limited.

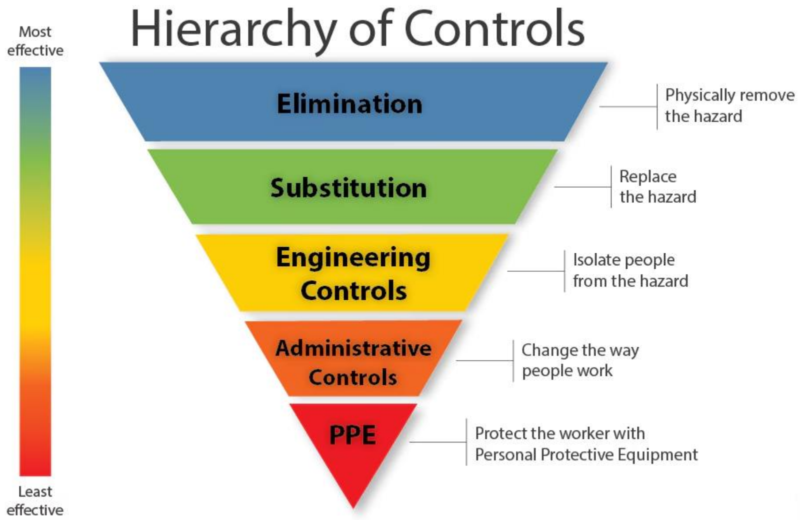

Figure 1. Hierarchy of noise control [17]

This study aims to perform acoustic measurements in the seat manufacturing unit, a part of the automotive industry with high sound pressure levels, and to determine the effects of the precautions that can be taken depending on the absorption of sound and the enclosure of the source on noise reduction. The effects of the precautions that can be applied in noise reduction are analyzed in a simulation environment, and their distributions are shown by the noise mapping method. A-weighted sound pressure levels, noise reduction values, and reverberation times at mid-frequency bands (500, 1000, 2000 Hz) for different scenarios were determined. Mid-frequency bands were used in the study since the sound level the human ear can hear sensitively occurs at mid-frequency bands.

2. Material and Methods

2.1. Case Study

The research selected the seat manufacturing unit of an automotive factory in Türkiye as a case study. The automotive factory is divided into main production halls, storage units, technical spaces, and administrative units. In the seat manufacturing unit, which is within the scope of the main production halls, fabric, foam, and coating processes are carried out for seat sets. The unit has an area of 2000 m^2, measuring approximately 50 m x 40 m. In the factory, the floor (lean concrete + coating), walls (metal panel), and ceiling (metal panel) are created with materials with high sound reflectivity. Accordingly, the hall in the case study creates an acoustic environment with high sound-reflecting properties. Additionally, the unit has a two-stage production process at ground and platform levels (Figure 2).

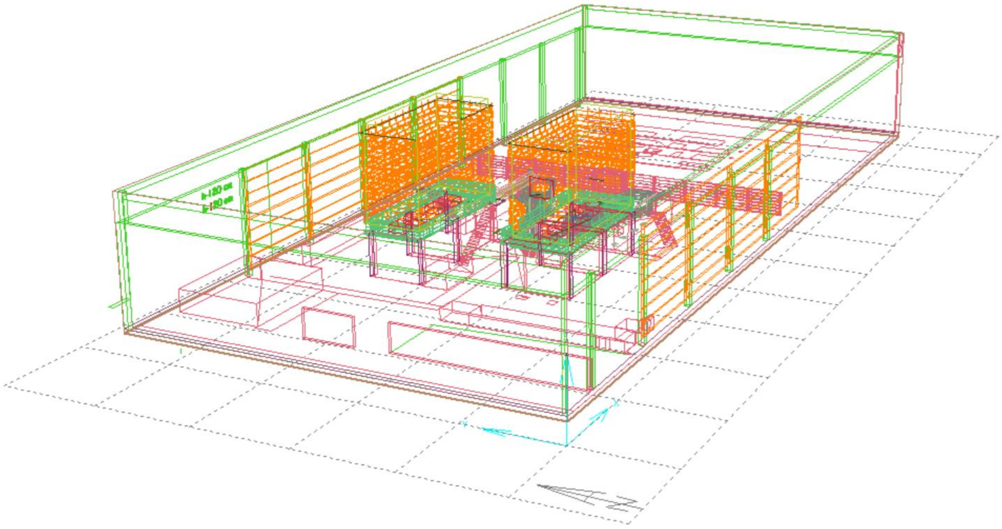

Figure 2. Seat manufacturing unit in the automotive industry

2.2. Acoustics Data Analysis and Simulations

Interior acoustic measurements were made in the seat manufacturing unit of the automotive factory. A sound level meter (testo 816-1, IEC 61672-1 Class 2) was used for acoustic measurements. Acoustic measurements were made in the seat manufacturing unit by ISO 9612:2009 standard, and A-weighted sound pressure levels were determined [23].

The seat manufacturing unit was modeled in the 3D computer environment. Existing machines (polyurethane filling machines, machines on platforms, vacuuming machines, and conveyors) were transferred to the model as sound sources. The acoustic environment of the unit was transferred to the simulation program (calibration) based on the sound pressure levels determined by acoustic measurements and the sound power levels in the catalog information of the existing machines. In the simulation program, surface sound absorption coefficients were defined following the properties of the finish materials of the building elements. Autodesk Ecotect v.5.20, a Building Information Modeling (BIM) software, was used as the simulation program. The simulation program used, Autodesk Ecotect, creates many random rays and examines the damping of the rays [24, 25]. This data generates the average damping curve for each frequency band in the spectrum distribution, and the environment's sound pressure level and reverberation time are calculated.

Various scenarios were created to reduce the A-weighted sound pressure levels, which are currently high. The effects of the scenarios on the indoor sound pressure level, the noise reductions, and reverberation times at mid-frequencies (500, 1000, 2000 Hz) were investigated. Existing ceiling materials were retained in the scenarios (due to intervention limitations). In the geometrical acoustic analysis investigated by simulation, 20000 beams with 12 reflections were used. The data obtained were analyzed using sound-absorbing panels on the wall and interior planes and by enclosing the machines on the platform and the results were evaluated.

A weighted sound pressure level used to compare the results of different scenarios expresses the relative loudness of sounds the human ear perceives. A-weighting first adjusts the measured octave-band decibel levels to account for human decreased sensitivity to sound levels at low frequencies, then uses decibel addition of the newly weighted sound level values at each octave band [26, 27]. Within the scope of the research, an A-weighted sound pressure level was used to determine the sound level of the current situation, and the simulation results were used to determine the ambient sound levels. Simultaneously, the simulation results were used as the difference between the current situation and the result in calculating the effect of simulation results on noise reduction.

The reverberation time used to determine the effect of surface absorption on acoustic comfort is determined by the volume of the space and the sound absorption coefficients and surface areas of the finish materials used [28]. Wallace C. Sabine (1868-1919) determined the examination of reverberation time in the control of room acoustic performance and made acoustic evaluations to strengthen the effect of auditory performances [29]. Different calculations approaches, and application areas have been developed in the historical process to determine the reverberation time. However, Sabine's equation is especially preferred and used in architectural and room acoustics [30, 31]. In this research, Sabine's equation analyzes the change of reverberation time at mid-frequencies (500, 1000, and 2000 Hz) over different noise reduction scenarios to be applied in the automotive industry. Using the optimum reverberation time for any parameter in industrial facilities is impossible. However, the change of reverberation time depending on the surface absorption is an effective parameter in noise reduction.

3. Results and Discussion

3.1. Acoustic Measurements

Sound pressure level measurements were made at various points (for employee positions) in the seat manufacturing unit of the automotive factory. Acoustic measurements revealed a sound pressure level distribution of 70-88 dBA on the floor and 60-80 dBA on the platform. It was observed that sound pressure levels increased in the sections close to the engines of the machines. With this situation, it has been determined that high noise exposure levels occur when machine and employee interaction is considered. Reducing sound pressure levels with rational and appropriate interventions in the indoor environment is necessary.

3.2. Acoustic Simulations

In the seat manufacturing unit of the automotive factory, solutions were developed to cover the structural elements with high sound reflective properties with materials with high sound absorption properties and to enclose the machines with high sound power levels in an insulated enclosure. For this purpose, a material with a high sound absorption coefficient (aw:1, ISO 11654) was selected and used in acoustic simulations [32] (Figure 3). An important criterion was that the material should be non-combustible (A2 - A) according to EN 13501-1 and ASTM E84 [33, 34]. Additionally, the material used in the automotive industry is impact-resistant and long-lasting.

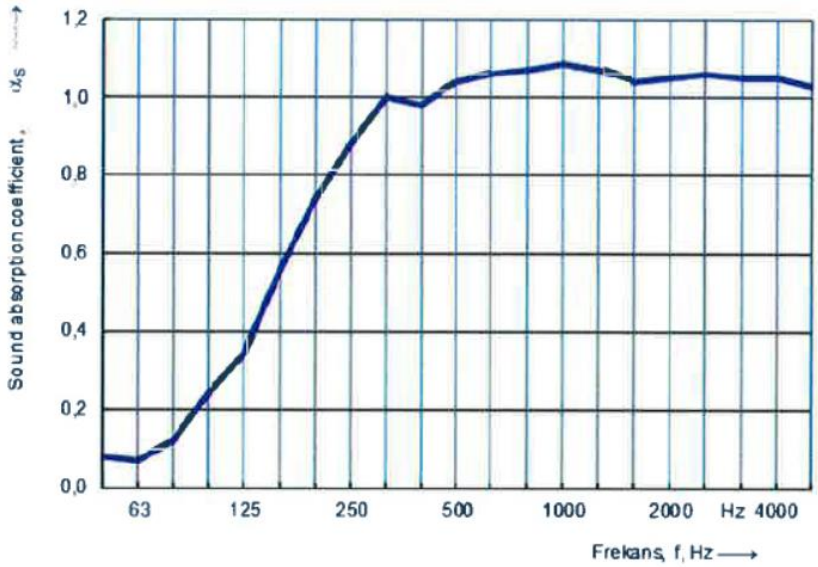

Figure 3. The sound absorption coefficient of the new material

Three different possible action scenarios for reducing sound pressure levels in the existing unit were developed, and their effects on indoor sound pressure levels, noise reduction, and reverberation times at mid-frequencies (500, 1000, 2000 Hz) on the ground and platform were investigated. The acoustic environment created by the rational solutions for the employees on the floor and platform was analyzed (Table 1).

Table 1. Scenarios for noise reduction and their effects on the acoustic environment

	Properties	SPL dB(A)	Noise Reduction (dB)	Reverberation Time, s		
				500 Hz	1000 Hz	2000 Hz
Current Situation	Seat manufacturing unit of the automotive factory with high reflective properties	Ground: 70-88 Platform: 60-80	-	13,03	16,70	9,64
Scenario 1	– Use of sound-absorbing materials on the walls surrounding the production unit (up to 9,20 m) – Enclosure with sound-absorbing material on the platform - the top is covered (h: 5 m) – *Use of sound-absorbing material on the sides of the mold cleaning bench (h: 2 m)** – *Use of sound-absorbing material on conveyor sides (h: 2 m)**	Ground: 50-65 Platform: 55-75	Ground: 20-23 Platform: 5	0,24	0,24	0,24
Scenario 2	– Use of sound-absorbing materials on the walls surrounding the production unit (up to 8 m) – Enclosure with sound-absorbing material on the platform - the top is uncovered (h: 3 m) – *Use of sound-absorbing material on the sides of the mold cleaning bench (h: 2 m)** – *Use of sound-absorbing material on conveyor sides (h: 2 m)**	Ground: 50-68 Platform: 55-70	Ground: 20 Platform: 5-10	1,74	1,75	1,67
Scenario 3	– Use of sound-absorbing materials on the walls surrounding the production unit (up to 8 m) – Enclosure with sound-absorbing material on the platform - the top is covered (h: 2 m) – *Use of sound-absorbing material on the sides of the mold cleaning bench (h: 2 m)** – *Use of sound-absorbing material on conveyor sides (h: 2 m)**	Ground: 54-72 Platform: 56-73	Ground: 16 Platform: 4-7	1,88	1,89	1,81

* Precautions that are the same in all scenarios are described.

In Scenario 1, it was determined that the A-weighted sound pressure levels were 50-65 dBA on the floor and 55-75 dBA on the platform by covering the walls surrounding the production area with sound-absorbing material (up to 9,20 m), enclosing the platform in an enclosure with sound-absorbing material (h: 5 m), covering the sides of the mold cleaning bench with sound-absorbing material (h: 2 m), covering the conveyor sides with sound-absorbing material (h: 2 m). The noise control methods applied for Scenario 1 and the resulting noise map were prepared (Figure 4). Noise reduction was approximately 20 dB on the ground and 5 dB on the platform. Reverberation times were 0,24 s for 500 Hz, 0,24 s for 1000 Hz, and 0,24 s for 2000 Hz.

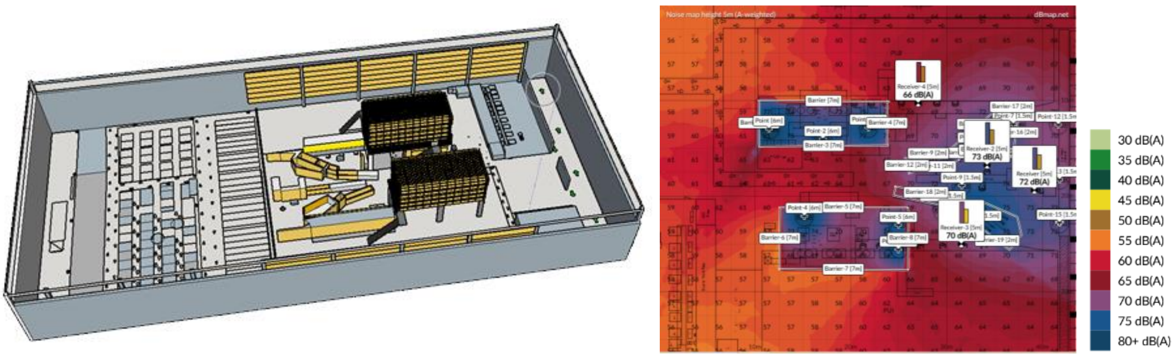

Figure 4. Noise control methods in Scenario 1 and the noise map created at a height of 1,5 m

In Scenario 2, it was determined that the A-weighted sound pressure levels were 50-68 dBA on the floor and 55-70 dBA on the platform with the processes of covering the walls surrounding the production area with sound-absorbing material (up to 8.00 m), enclosing the platform in an open cell with sound-absorbing material (h: 3 m), covering the sides of the mold cleaning bench with sound-absorbing material (h: 2 m), covering the conveyor sides with sound-absorbing material (h: 2 m). The noise control methods applied for Scenario 2 and the resulting noise map were prepared (Figure 5). Noise reduction was determined as 20 dB on the ground and approximately 5-10 dB on the platform. Reverberation times were 1,74 s for 500 Hz, 1,75 s for 1000 Hz, and 1,67 s for 2000 Hz.

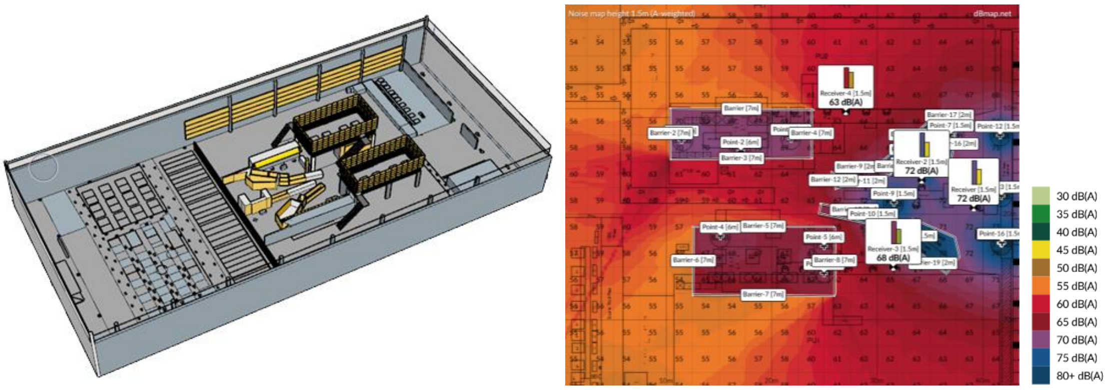

Figure 5. Noise control methods in Scenario 2 and the noise map created at a height of 1,5 m

In Scenario 3, it was determined that the A-weighted sound pressure levels were 54-72 dBA on the floor and 56-73 dBA on the platform with the processes of covering the walls surrounding the production area with sound-absorbing material (up to 8,00 m), enclosing the platform in an open cell with sound-absorbing material (h: 2 m), covering the sides of the mold cleaning bench with sound-absorbing material (h: 2 m), covering the conveyor sides with sound-absorbing material (h: 2 m). The noise control methods applied for Scenario 2 and the resulting noise map were prepared (Figure 6). Noise reduction was determined as 16 dB on the ground and approximately 4-7 dB on the platform. Reverberation times were 1,88 s for 500 Hz, 1,89 s for 1000 Hz, and 1,81 s for 2000 Hz.

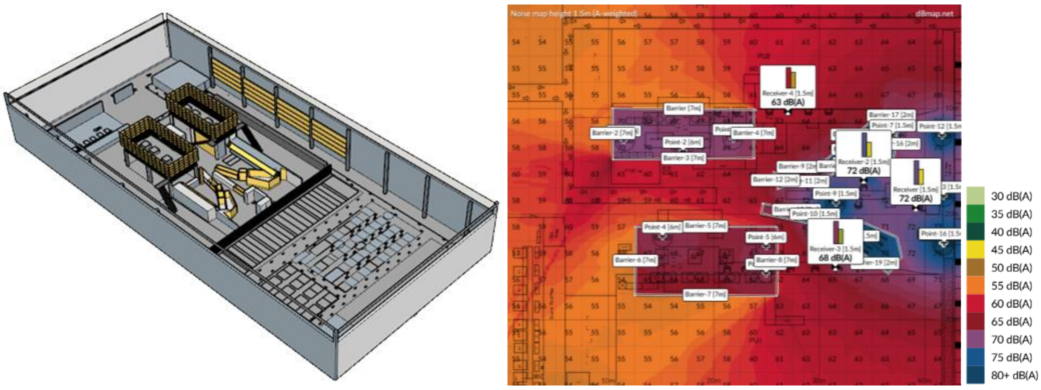

Figure 6. Noise control methods in Scenario 3 and the noise map created at a height of 1,5 m

Sound pressure level controls were carried out in two steps in the seat manufacturing unit of the automotive factory. In enclosed room conditions, it is aimed to prevent sound waves from increasing the sound pressure level in the environment by reflections. Accordingly, a suitable acoustic environment was created by reducing the reverberation time. Scenario 1 was created with the noise control methods on the current situation, possible interventions and variables were applied, and scenario 2 and scenario 3 were obtained. The precautions applied on the floor for noise control achieved a success of over 15 dB. However, the noise control measures applied on the platform achieved only 5-10 dB. The location of the machines (sound sources) close to the platform and the fact that the ceiling could not be intervened in the case study effectively achieved these results.

Additionally, noise reduction with sound absorption in the enclosure method yielded effective results. Using the enclosure as a noise barrier with sound absorption properties has created an effective sound absorption property in the enclosure method. The noise levels inside the enclosure evidence are higher than the existing environment in the noise maps. It has been observed that in the enclosure method, the closed top and the enclosure's high height provide the most effective sound absorption. Accordingly, the reverberation time at mid-frequencies is greatly decreased. Compared to planar sound-absorbing panels inside the room, it was observed that enclosing sound sources in isolated enclosures provides more effective results.

4. Conclusion

Seat manufacturing units in automotive factories create noisy working environments with high sound pressure levels. Precautions need to be taken to protect employees' health and eliminate noise. For this purpose, various noise control precautions are applied at the source, transmission path, and receiver. However, the most applicable methods for existing buildings are detailed with precautions to be taken directly in the transmission path. Intervening in the reverberant sound field with the principle of sound absorption is sufficient to provide the required reduction values on the floor and platform in the unit. The use of sound-absorbing materials in the room and the enclosure of sound sources effectively create a suitable and quieter acoustic environment. Preventing the spread of sound into the space with the enclosure method and absorbing it inside the enclosure plays an important role in shaping the sound pressure level distribution of the environment. It should be known that the reverberation time, which cannot be used as a direct objective parameter in factories, may vary according to the sound absorption capacity of the environment. It is planned to test alternative scenarios in different simulation tools and analyze the success rates of simulation results by creating the scenario results in the facilities. Moreover, it is recommended to investigate the acoustic characteristics of other automotive industry units and the effects of different noise control precautions on the acoustic environment in various units.

Author Contributions

The first and second authors devised the main conceptual ideas and developed the theoretical framework. The first and second authors performed the experiment and simulation analyses. The first author wrote the manuscript with support from the second author. The second author reviewed and edited the paper. All authors read and approved the final version of the paper.

Conflicts of Interest

All the authors declare no conflict of interest.

Ethical Review and Approval

No approval from the Board of Ethics is required.

References

[1] I. Alimohammadi, F. A. Kanrash, J. Abolaghasemi, H. Afrazandeh, K. Rahmani, *Effect of chronic noise exposure on aggressive behavior of automotive industry workers*, International Journal of Occupational Environmental Medicine 9 (2018) 170–175.

[2] Y. Chen, M. Zhang, W. Qiu, X. Sun, X. Wang, Y. Dong, Z. Chen, W. Hu, *Prevalence and determinants of noise-induced hearing loss among workers in the automotive industry in China: A pilot study*, Journal of Occupational Health 61 (5) (2019) 387–397.

[3] M. Yaman, C. Kurtay, G. Ulukavak Harputlugil, *Acoustical environments in the textile industry facilities: A case study of Malatya Province, Türkiye*, In Proceedings of INTER-NOISE 2023, Chiba, Greater Tokyo, Japan, 2023.

[4] E. Atmaca, I. Peker, A. Altin, *Industrial noise and its effects on humans*, Polish Journal of Environmental Studies 14 (6) (2005) 721–726.

[5] M. D. Fernández, S. Quintana, N. Chavarría, J. A. Ballesteros, *Noise exposure of workers of the construction sector*, Applied Acoustics 70 (2009) 753–760.

[6] C. Rinjea Costache, O. R. Chivu, A. I. Țăpîrdea, A. Feier, L. Dascălu, A. C. Firu, C. Babis, *Professional exposure to noise in the automotive industry*, Journal of Research and Innovation for Sustainable Society 2 (2) (2020) 37–42.

[7] S. I. Monye, S. A. Afolalu, S. L. Lawal, T. T. Gisanrin, O. A. Oluwatoyin, A. G. Adeyemi, *Now and future challenges of the automobile industry in the developing world*, In Proceedings of E3S Web of Conferences, 430, ICMPC, 2023.

[8] H. M. V. Montemayor, R. H. Chanda, *Automotive industry's circularity applications and industry 4.0*, Environmental Challenges 12 (2023) 100725.

[9] Z. Wang, J. Liang, X. Rong, H. Zhou, C. Duan, W. Du, Y. Liu, *Noise hazard and hearing loss in workers in automotive component manufacturing industry in Guangzhou, China*, Chinese Journal of Industrial Hygiene and Occupational Diseases 33 (12) (2015) 906–909.

[10] L. Luo, J. Jiang, S. L. Huang, J. He, J. M. Li, *Analysis on characteristics of hearing loss in occupational noise-exposed workers in the automotive manufacturing industry*, Chinese Journal of Industrial Hygiene and Occupational Diseases 36 (6) (2018) 445–448.

[11] D. P. Duan, L. X. Bai, C. X. Qiu, T. Y. Huang, S. H. Tang, Y. M. Liu, *Combined effect of noise and hand-transmitted vibration on noise-induced hearing loss in the automobile manufacturing industry*, Chinese Journal of Industrial Hygiene and Occupational Diseases 38 (6) (2020) 420–423.

[12] Y. X. Tang, Y. R. Li, C. W. Duan, S. F. Hou, J. Y. Wang, Y. M. Liu, *Characteristics at different frequencies of hearing loss in noise exposure workers of the automobile manufacturing industry*, Chinese Journal of Industrial Hygiene and Occupational Diseases 39 (4) (2021) 266–269.

[13] N. A. M. Zulkefli, M. F. Rusli, A. A. Rahman, *Predictors of knowledge, attitude, and practice of noise induced hearing loss among workers in an automotive industry in Malaysia*, Malaysian Journal of Medicine and Health Sciences 13 (1) (2017) 61–68.

[14] Ü. Taş, E. Pak, B. Uğur, *Recent engineering applications for noise reduction in an automotive industry*, Journal of Advanced Research in Natural and Applied Sciences 10 (1) (2024) 207–217.

[15] W. W. Lang, G. C. Maling, *Noise as a technological and policy challenge*, The Bridge National Academy of Engineering 37 (3) (2007) 4–10.

[16] A. D. Bies, C. H. Hansen, Engineering noise control theory and practice, 3rd Edition, London, New York, E and FN Spon Press, 2003.

[17] NIOSH, National Institute for Occupational Safety and Health, Url: https://www.cdc.gov/niosh/hierarchy-of-controls/about/index.html Accessed 18 July 2024

[18] M. Mokhtar, S. Kamaruddin, Z. A. Khan, Z. Mallick, *A study on the effects of noise on industrial workers in Malaysia*, Jurnal Teknologi 46 (A) (2007) 17–30.

[19] E. K. Putro, S. Mangkoedihardjo, N. Karnaningroem, E. S. Pandabessi, A. D. Syafei, *Industrial noise mapping: Literature review, designed for new plant operation*, In Proceedings of E3S Web of Conferences, ICENIS 2023, 448, 03059, (2023).

[20] N. Ilgürel, *Effectiveness of the total absorption on noise reduction in industrial plants*, Noise Control Engineering Journal 61 (1) (2013) 11–25.

[21] R. Golmohammadi, M. R. Monazzam, Z. Hashemi, S. M. B. Fard, *Pattern evaluation of noise propagation at various units of a textile industry*, Caspian Journal of Applied Sciences Research 3 (6) (2014) 1–8.

[22] M. Kavraz, and R. Abdulrahimov, *A study comparing the noise reduction behavior of variously shaped barriers of limited size in indoor spaces*, Indoor and Built Environment 18 (6) (2009) 541–552.

[23] ISO 9612:2009 Acoustics - Determination of occupational noise exposure engineering method, International Organization for Standardization, Genève, 2009.

[24] A. Tokuc, *Building energy simulation tools and selection criteria*, Dokuz Eylül University Faculty of Engineering Journal of Science and Engineering 11 (2) (2009) 19–30.

[25] G. Riether, T. Butler, *Simulation space: A new design environment for architects*. In Proceedings of Section 03: Prediction and Evaluation 1 - eCAADe 26 (2008) 133–142 2008.

[26] M. Ermann, Architectural acoustics illustrated, John Wiley and Sons, Inc., 2015, pp. 17--22.

[27] K. Genuit, W. Bray, G. Caspary, *Comparison of a-weighted sound pressure level (dB(A)), loudness-level weighted sound pressure level (dB(EQL)), and loudness with respect to environmental noise assessment*, The Journal of the Acoustical Society of America 128 (4) (2010) 2469.

[28] C. Kurtay, G. Harputlugil, M. Yaman, *Effects of sound absorption materials on reverberation time according to their positions in the square plan and high ceiling rooms*, Journal of the Faculty of Engineering and Architecture of Gazi University 36 (4) (2021) 2069-2080.

[29] W. C. Sabine, *Collected papers on acoustics*, London, Humphrey Milford, Oxford University Press, England, 1922.

[30] L. L. Beranek, *Analysis of Sabine and Eyring equations and their application to concert hall audience and chair absorption*, The Journal of the Acoustical Society of America 120 (2006) 1399–1410.

[31] A. Nowoświat, and M. Olechowska, *Investigation studies on the application of reverberation time*, Archives of Acoustics 41 (1) (2016) 15–26.

[32] EN ISO 11654, Acoustics - Sound absorbers for use in buildings - Rating of sound absorption, International Organization for Standardization, Genève, 1997.

[33] EN 13501-1:2018, Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests, European Committee for Standardization, Brussels, 2018.

[34] ASTM E84, Standard test method for surface burning characteristics of building materials, American Society for Testing and Materials, U.S. Department of Defense, USA.