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Research Article

Cost-benefit analysis of ergonomics-sustainability projects with analytic hierarchy process

Analitik hiyerarşi süreci ile ergonomi-sürdürülebilirlik projelerinin maliyet-fayda analizi

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Abstract

Today, sustainability gets a top priority on the agenda of the shortage of natural resources and regulations. Managers seek how to give minimum damage to the environment while keeping productivity. Ergonomics has an answer to trying to smooth the relationships between man and the elements of a system to optimize the whole system's performance and human satisfaction. Ergonomics and sustainability have common areas of interest in putting a man into the centre. Managers always seek ways to improve productivity but investing in employee wellness is often ignored. They are hesitant to fund projects like ergonomics and environmental until savings are proven. The proposed model in this study using Cost-Benefit Analysis (CBA) and Analytic Hierarchy Process (AHP) together may convince the decision makers to approve the ergonomics or environmental projects easily, which are seen as a pure expense at first.

Keywords: Cost-Benefit Analysis, Analytic Hierarchy Process, Project Evaluation

Jel Codes: D61, H43, M10

Öz

Günümüzde, doğal kaynakların ve düzenlemelerin yetersizliği nedeniyle sürdürülebilirlik gündemin en üst sıralarında yer almaktadır. Yöneticiler, üretkenliği korurken çevreye nasıl daha az zarar verebileceğimi sorguluyorlar. Ergonominin, bütün sistem performansını ve insan memnuniyetini optimize etmek için insan ve sistemin öğeleri arasındaki ilişkileri uyumlaştırmaya çalışan bir cevabı vardır. Ergonomi ve sürdürülebilirliğin, insanı merkeze alma konusunda ortak ilgi alanlarına sahiptir. Yöneticiler her zaman üretkenliği artırmanın yollarını arar, ancak çalışanların iyiliğine yatırım yapmayı genellikle göz ardı ederler. Projede tasarruf kanıtlanana kadar ergonomi ve çevre gibi projeleri finanse etmekte tereddüt ederler. Maliyet-Fayda Analizi (MFA) ve Analitik Hiyerarşi Sürecinin (AHS) birlikte kullanıldığı bu çalışmada önerilen model, karar vericileri, başta tamamen ilave harcama olarak görülen ergonomi veya çevre projelerini kolayca onaylamaya ikna edebilir.

Anahtar Kelimeler: Fayda-Maliyet Analizi, Analitik Hiyerarşi Süreci, Proje Değerlendirme

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Introduction

Sustainability refers to the continuation of human life while ensuring production and diversity. People's lives are based on natural resources. However, the natural resources our lives depend on do not have an infinite feature. The importance of sustainability means ensuring sustainability and aiming to build a balance between nature and humans (Johnston, Everard, Santillo & Robèrt., 2007). Sustainability encourages decision-makers to take long-term actions in environmental, social, and human issues rather than short-term gains.

Ergonomics as a tool to support sustainability is a way of designing work systems to accommodate the capabilities of workers. Human well-being and overall system performance emerge as the common goals of sustainability and ergonomics. Ergonomics projects have a beneficial impact on building a sustainable working environment, reducing the probability of injury or accident, turnover rate and absenteeism while improving workers' productivity and morale (Pavlovic-Veselinovic, 2014). Ergonomics is an effective tool for improving sustainability while reducing the negative effects of industry on the ecosystem.

A workplace injury in business must be taken as a warning sign that one or more factors are deficient. The cost of a workplace injury can be direct or indirect. Medical expenses and worker's compensation payments are examples of direct costs. Decreasing work time, productivity, work quality and morale constitute indirect costs.

Ergonomics is used to redesign a working system in a business to improve productivity and safety. That kind of intervention needs investing funds, and to justify the expense, it must be clarified about returning benefits of the program to be funded. The question to be answered is, is it a worthwhile investment for organizations? Does it pay off?

Evaluating the costs of ergonomics projects is easier than the benefits because many cost factors are ready in the organization (Hendrick, 2003). However, Hendrick (1997) stated in his study, "at first glance, it appears that a conflict exists in organizational practice between the requirements of an ergonomic approach and the consideration of economic conditions and that therefore both perspectives are only to be reconciled via a trade-off".

Ergonomic programs are not a cost for organizations; rather, they reduce costs over time dramatically. But at the very first step, funding is seen as barrier organizations have faced in managing ergonomic programs. So to get decision-makers approval for ergonomics programs, a detailed feasibility report must be prepared and presented while requesting and receiving funding approval.

Cost-Benefit Analysis (CBA) is one of the most commonly used techniques in financial evaluating projects in business. On the other hand, it will be helpful to use Analytic Hierarchy Process (AHP) to elevate subjective parts of projects and give more realistic decisions. AHP will enable decision-makers to set priorities and evaluate the projects according to conditions. This article constitutes a unique study combining ergonomics, sustainability, CBA and AHP and leads to a clear picture of the project evaluating process in business.

In the literature review section, detailed information was given about the sub-topics of the study sustainability, project evaluation, ergonomics, CBA and AHP, respectively. Then, in the application and results section, CBA and AHP were applied to two sample ergonomics projects, and all iterations were illustrated step by step. Finally, in the conclusion section, the results were interpreted and discussed.

Literature review

The literature has not encountered a study proposing a model using AHP and CBA together on sustainability and ergonomics. However, there are studies covering two or three subjects partially.

There are very few studies on ergonomics and sustainability. One of them is Haslam & Waterson (2013) stated that before 2000, ergonomics was assumed to be an interdisciplinary science symbolizing western liberal capitalism, just focusing on productivity issues and disregarding planet interactions. However, when the world encounters fatal environmental implications, classical productivity studies began addressing global ergonomics with sustainable development.

There are considerably more studies on sustainability or ergonomics issues using AHP or CBA technique. For AHP methodology, Taha, Abdul Salaam, Sin Ye, Tuan, & Mohamad (2015) studied material design to support sustainability with AHP using three criteria: production costs, carbon emission rate and ergonomic evaluation, to find the best possible decision according to the given criteria. Waris, Panigrahi, Mengal, Soomro, Mirjat, Ullah, Azlan, & Khan (2019) developed a framework with AHP on sustainable procurement to take a more sensible decision with six criteria: environmental impact, life cycle cost, social benefits procurement, performance, system capability and operational convenience. Jayawickrama, Kulatunga & Mathavan (2016) studied plant sustainability by fuzzy AHP and proposed a sustainability evaluation tool. Mani, Rajat & Vinay (2014) researched social sustainability using the AHP methodology. The study results guided managers to integrate many dimensions, such as health, equity, safety, wages and education, into the supply chain management system.

For CBA methodology, Soderqvist, Brinkhoff, Norberg, Rosen, Back & Norrman (2015) made a CBA as a part of sustainability assessment and guided decision makers on investment decisions of contaminated areas. Goggins, Spielholz & Nothstein (2008) made a case study on estimating the effectiveness of ergonomics programs with CBA. The results showed that the main benefits of ergonomic programs were positive, and the payback period was less than one year.

Sustainability and ergonomics

Sustainability is a comprehensive approach considering the ecological, social and economic factors. Sustainable development is a social justice project that focuses on equitable development to meet human needs and emphasizes the need to protect natural resources to meet these needs (Johnston et al. 2007). Sustainability is the concept that products must be designed to be recycled, remanufactured and reused to build stability among environmental, economic and sociocultural factors (Pavlovic-Veselinovic, 2014).

Aksoy (2013) stated in his thesis the reasons why sustainable development is so important for businesses today as;

- The growth of businesses has brought environmental responsibilities.
- Investors are now taking into account the environment for the entire supply chain line,
- Consumers are becoming more conscious of environmental issues,
- Climate changes force companies to be sensitive to these issues.

Ergonomics is the scientific discipline concerned with understanding interactions among humans and other elements of a system and the profession that applies theory, principles, data, and methods to design to optimize human well-being and overall system performance (IEA, 2020).

The new trend in ergonomics is called green ergonomics, which refers to supplying human and natural system balance by comprehending their mutual relationships. According to this ergonomics approach, sustainable human welfare and effectiveness cannot be mentioned when the natural environment is spoiled and exhausted. Therefore, it aims to reduce man's negative effects on the ecosystem through ergonomic and sustainable interventions. Furthermore, it examines ways to cope with nature's healing and original features in the design of workplaces, cities, etc. According to Thatcher (2013), the topics of this new approach of ergonomics are; less resource-consuming job design (green work), design of systems and products consuming fewer resources (green systems and green products) and studies to increase environmental awareness.

The intersection of sustainability and ergonomics is the social goal (human well-being) and economic goal (overall system performance). Sustainable economic growth is viable if it pushes forward the quality of life, which is also the common aim of ergonomics and sustainability. So ergonomics is closely related to sustainability.

Project evaluation

Project management (PM) uses knowledge, abilities, tools, and techniques to supply the project requirements. PM steps are; initiating, planning, executing, monitoring and controlling and closing (Darnall & Preston, 2012).

Initiating step is the first step and describes the goals and feasibility of the project. Project evaluation is done in this step. Frechtling (2002) stated in his handbook that “evaluation of the project involves an assessment of the project, policy, program or investments, taking into account all its stages: planning, implementation, and monitoring of results. At the end of the evaluation phase, the decision makers will make a yes/no meeting to continue the project or reject it. If the decision is continued, the other project management steps will be conducted”. As the focus of this article is project evaluation of ergonomics projects, the details of project evaluation are explained next while masking the other project management steps.

To give a realistic, cost-effective allocation decision, managers should evaluate the feasibility of project alternatives according to their priorities, such as cost, benefit, ease of use, legal requirements etc. In the literature, there are two project evaluation methods which, one is static methods, and another one is dynamic methods.

Static project evaluation methods are simple and easy to use from the calculation point because their principle is based on the acting year effects, neglecting the time as a factor. Frequently used static methods are; CBA, the payback period and the rate of return on investment (ROI). On the other hand, dynamic project evaluation methods are used in more complex projects as a second classification. The most frequently used methods are; net present value (NPV), internal rate of return (IRR), modified internal rate of return (MIRR) and annuity method of depreciation. In this study, CBA is selected as a financial project evaluation method because of its simplicity and ease of use. Detailed information about CBA is given next section.

CBA

CBA is simply adding the benefits and subtracting the costs of a project (Zavitz, 2019). In other words, CBA is a systematic approach to estimating alternatives' strengths and weaknesses to determine options that provide the best decision (David, Ngulube, & Dube, 2013; Mommoh, 2018). The purpose of CBA is to present a systemic approach to calculate the pluses and minuses of a project. Then, it gives you options and offers the best alternative to your aim according to your priorities.

Hendrick (2003) lists the costs of ergonomics projects as personnel, equipment and materials, and overhead.

- Personnel costs include external consultants, internal personnel and employee downtime.
- Equipment and materials costs are equipment, and materials are purchased or produced internally.
- Overhead costs are the other costs, including maintenance, rent, and general administrative expenses. Generally, ergonomics applications will reduce overhead costs.

Hendrick (2003) lists the benefits of ergonomics projects as personnel, equipment and materials, and intangible benefits.

- Personnel-related benefits are increasing the output, reducing the error rate, reducing accidents and injuries, reducing training requirements, reducing skill requirements, reducing maintenance, reducing absenteeism and reducing turnover rate.
- Equipment and materials benefits are reduced scrap, equipment savings, reduced maintenance and reduced equipment damage.
- Intangible benefits are such as increasing labour commitment and improving corporate image.

AHP

Mammoth (2018) describes AHP as structuring the decision hierarchically to reduce complexity and show relationships between criteria and alternatives. It also includes intangibles such as experience, preferences etc.

AHP is a problem-solving tool having three levels. The first level describes the problem encountered, and the second level depicts the alternative solutions to the problem. The third level is the parameters used to evaluate the solutions. Several criteria may exist, but each may have a different level of importance (Saaty & Luis, 2012; Saaty, 2001).

Managers need to measure tangible and intangible aspects of the problems or projects. The AHP is a method that can fill up this area by evaluating measures in both the tangible and intangible aspects of the problem.

Mu & Pereyra-Rojas (2016) proposed six steps to analyse the decision-making using the AHP as;

Step1. Develop a model by breaking down the decision into a hierarchy of goals, criteria, and alternatives,

Step 2. Derive priorities (weights) for the criteria,

Step 3. Derive local priorities (preferences) for the alternatives,

Step 4. Derive overall priorities (model synthesis), Step 5. Perform sensitivity analysis

Step 6. Make a final decision.

Methodology

In this study, it is given two sample ergonomics projects for an organization to be evaluated financially. The main properties of the projects are as Table 1.

Table 1: Cost and Benefit Properties of Projects

Properties	Projects 1	Projects 2
Costs		
Personnel	High	Moderate
Equipment and material	Low	Moderate
Overhead	Moderate	High
Benefits		
Personnel	High	Moderate
Equipment and material	Moderate	Low
Intangible benefits	High	Low

Model derivation

In the AHP model, the first level is the goal, the second level is the criteria, and the third is the alternatives. According to the properties given in Table 1 for two sample projects, AHP models of the project's costs and benefits are constructed in Figures 1 and 2 as follows.

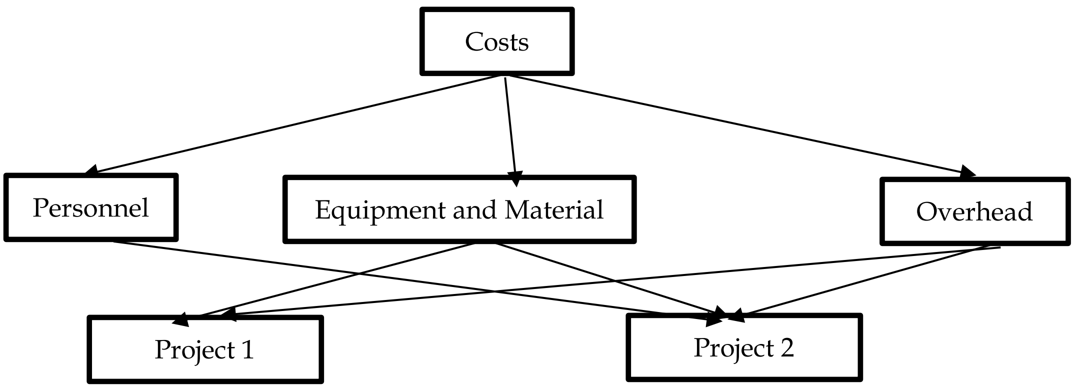

Figure 1: Cost Benefit Analysis AHP Model Projects (Costs)

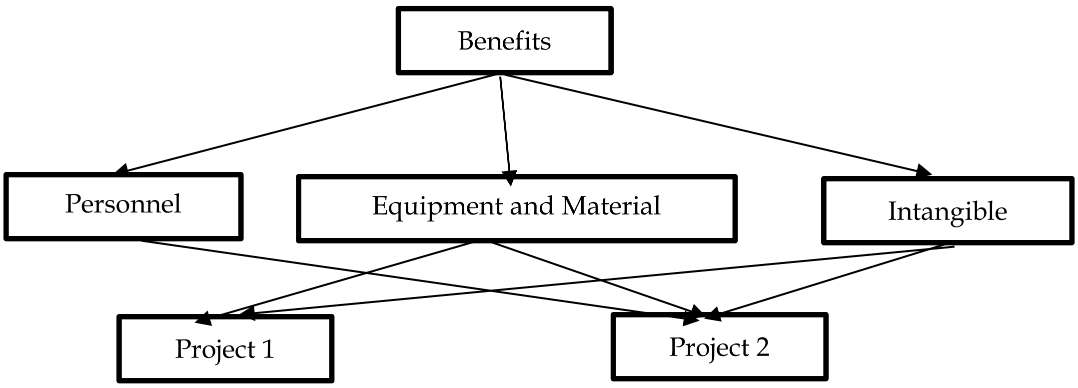

Figure 2: Cost Benefit Analysis AHP Model Projects (Benefits)

Properties of projects determined by decision-makers in Table 1 will be converted to numerical values using the scale in Table 2.

Table 2: Pairwise Comparison Scale

Verbal judgment	Numeric value
Extremely important	8,9
Very Strongly more important	6,7
Strongly more important	4,5
Moderately more important	2,3
Equally important	1

Note. Saaty, T. (1980). The Analytic Hierarchy Process. McGraw-Hill, New York., 1980

It is assumed that the evaluating committee made judgements for cost and benefit factors as below:

- Personnel cost is strongly more important,
- Personnel cost is very strongly more important than overhead cost,
- Equipment and material cost is strongly more important than overhead cost.
- Personnel benefit is moderately more important than equipment and material benefit,
- Personnel benefit is very strongly more important than intangible benefit,
- Equipment and material benefit are strongly more important than intangible benefits.

Results

Calculations

Normalization of values is calculated by dividing every cell by the total row of Table 3.

Table 3: Pairwise Comparison Matrix of Costs and Benefits

Costs	**Personnel**	**Equipment and material**	**Overhead**
Personnel	1	5	7
Equipment and material	1/5	1	5
Overhead	1/7	1/5	1
Total	1.343	6.200	13
Benefits	**Personnel**	**Equipment and material**	**Intangible benefits**
Personnel	1	3	7
Equipment and material	1/3	1	5
Intangible benefits	1/7	1/5	1
Total	1.476	4.200	13

Priority values are calculated simply by taking the average of each row.

Table 4: Normalized Comparison Matrix of Costs and Benefits

Costs	**Personnel**	**Equipment and material**	**Overhead**	**Priority**
Personnel	0.745	0.806	0.538	**0.696**
Equipment and material	0.149	0.161	0.385	**0.232**
Overhead	0.106	0.033	0.077	**0.072**
Benefits	**Personnel**	**Equipment and material**	**Intangible benefits**	**Priority**
Personnel	0.678	0.714	0.538	**0.643**
Equipment and material	0.226	0.238	0.385	**0.283**
Intangible benefits	0.096	0.048	0.077	**0.074**

According to the results of Table 3 and Table 4, it can be understood that personnel cost and personnel benefits are the most important factors. The priorities are determined according to the judgments and preferences in Table 1. In Table 4, it can be interpreted that personnel cost has 69.6 % of the real importance of the cost while personnel benefit has 64.3 % of the real importance of the benefit respectively. The other important values can be seen in the "priority column" of Table 4.

Consistency computation

It is impossible to get rid of inconsistencies completely because the numeric values are taken from the subjective judgements of managers. According to Mu & Pereyra-Rojas (2016) and Saaty & Luis (2012), AHP calculates a consistency ratio (CR) comparing the consistency index (CI) of the matrix in question (the one with our judgments) versus the consistency index of a random-like matrix (RI). RI value for matrices having three criteria is 0.58, and the CR formula is defined as

$$CR = CI/RI \tag{1}$$

If the CR value in equation (1) is 0.10 or less, then it is acceptable to continue with the analysis. Otherwise, it is necessary to make revisions to the analysis.

Table 5: Priorities as Factors and Weighted Sum

Cost	Personnel	Equipment and material	Overhead	Weighted sum
Personnel	0.696	1.160	0.216	**2.072**
Equipment and material	0.139	0.232	0.360	**0.731**
Overhead	0.099	0.046	0.072	**0.217**
Benefit	**Personnel**	**Equipment and material**	**Intangible benefits**	**Weighted sum**
Personnel	0.643	0.849	0.518	**2.010**
Equipment and material	0.214	0.283	0.370	**0.867**
Intangible benefits	0.092	0.056	0.074	**0.222**

Priorities as factors can be calculated simply by multiplying each row element of Table 5 with the original judgement from Table 3. by priority number (i.e., 1x0.696=0.696, 0.200x0.0.696=1.139). The weighted sum is equal to adding all cost row elements together. Then the weighted sum of each cost row will be divided by priorities of each column as 2.072/0.696= 2.977, 0.731/0.232= 3.150 and 0.217/0.072=3.013, respectively.

λ_max is calculated by adding up all three resulting numbers and dividing by three, which makes 3.047. CI is found by using the equation (2) where n=3

$$CI = (\lambda_{max} - n)/(n - 1) \text{ -1)} \tag{2}$$

and CI = (3.047-3)/2=0.023. CR for cost factor is found using equation (1) as (0.023/0.58) =0.039.

When the same procedure is applied to benefit factors, the results are calculated as: 2.010/0.643=3.125, 0.867/0.283= 3.063 and 0.222/0.074 =3.000. Then, CI for benefit is found as (3.062-3)/2=0.020 and CR for benefit as (0.020/0.58) =0.034. Since these values of 0.039 and 0.034 for CR are smaller than 0.10, it can be assumed that calculations are reasonable, which means AHP models are verified.

Deriving local preferences between projects

In a model having two alternatives (Project 1 and Project 2), one comparison is needed. According to Table 6:

- If personnel cost were the only criterion, then Project 1 would be the best option (priority = 0.833),
- If the only criterion were equipment and material cost, then the best choice would be Project 2,
- If the only criterion were overhead cost, then the best option would be Project 2,
- If the only criterion were personnel benefit, Project 1 would be the best choice (priority = 0.833),
- If the only criterion were equipment and material benefit, the best choice would be Project 1,
- and finally, if the only criterion were an intangible benefit, the best choice would be Project 1.

Table 6: The Results of Local Preferences

Cost	Personnel	Equipment and material	Overhead
Project 1	0.833	0.167	0.125
Project 2	0.167	0.833	0.875
Benefit	**Personnel**	**Equipment and material**	**Intangible**
Project 1	0.833	0.750	0.875
Project 2	0.167	0.250	0.125

Model synthesis

Local priorities show the preferred project according to each criterion. Model synthesis calculates each alternative's "overall priority" (Mommoh, 2018). According to Table 7, for cost criteria, Project 1 is preferable ("overall priority" = 0.812) compared to Project 2 ("overall priority" = 0.188). Similarly, benefit criteria (personnel, equipment and material, and intangible, again Project 1 is preferable ("overall priority" = 0.628) compared to Project 2 ("overall priority" = 0.372).

Table 7: The Results of Overall Priority

Cost	Personnel	Equipment and material	Overhead	
Criteria weights	0.643	0.283	0.074	**Overall priority**
Project 1	0.535	0.212	0.065	**0.812**
Project 2	0.107	0.071	0.009	**0.188**
Benefit	**Personnel**	**Equipment and material**	**Intangible**	
Criteria weights	0.696	0.232	0.072	**Overall priority**
Project 1	0.580	0.039	0.009	**0.628**
Project 2	0.116	0.193	0.063	**0.372**

As a result of all calculations, it is clear that Project 1 is eligible to be selected according to to cost and benefit criteria. Next, sensitivity analysis will be applied to make the final decision.

Sensitivity analysis

The "overall priorities" will be influenced by the "importance weights" given to each criterion. Hendrick (2003) defined sensitivity analysis as a what-if analysis to see how the final results would have changed if the criteria weights had been different. No final decision should be made without performing a sensitivity analysis. According to Mommoh (2018), the questions should be What would be the best alternative if we change the importance of the criteria? To make a sensitivity analysis, change the "weights of each criterion" and test how they impact the "overall priorities" of the alternatives.

There will be two scenarios for the evaluation process of the study:

- Scenario 1: original overall priorities reached by previous calculations in Table 5.
- Scenario 2: it is given the same value for all criteria (each factor has 0.333 weight)

In scenario one, the results were found for the cost factor for Project 1=0.812 and Project 2=0.188, for the benefit factor for Project 1=0.628 and Project 2=0.372. Similarly, in scenario two, the results for cost factor were found for Project 1=0.375 and Project 2=0.625, for the benefit factor for Project 1=0.818 and Project 2=0.182.

It is now possible to make a final decision. This is the last step of the study. The resulting ratio for Project 1 for scenario 1 is 0.812/0.628=1.292 and for Project 2 is 0.188/0.372=0.505. This result shows project 1 is a better option than project 2 in scenario one according to all computations.

Likewise, Project 1 for scenario 2 is 0.375/0.818=0.458 and Project 2 is 0.625/0.182=3.434. This result shows project 2 is a better option than project 1 in scenario two according to all computations.

Conclusion

Ergonomics and sustainability are closely related fields that mutually support each other (Haslam & Waterson, 2013). For example, ergonomics applications help sustainability by improving human resources sustainability, such as increasing motivation, improving safety in workstations, decreasing absenteeism, and decreasing accidents and injuries. Besides, it contributes to sustainability by decreasing scrap and waste. On the other hand, sustainability awareness and consciousness encourage using ergonomics programs in organizations (Pavlovic-Veselinovic, 2014).

At first, ergonomics and environmental projects may easily be seen as a pure expense. This study proposed a model that AHP and CBA will be used together to overcome this illusion. It is concluded that CBA gives a very well-structured framework for complex projects in business, including tangible and intangible costs and benefits in the project evaluation process (Goggins et al., 2008). On the other hand, AHP contributes to forming a hierarchal model from the designing phase of the project evaluation procedure through the end of giving the final decision. Besides, AHP elevates the subjective preferences of human interventions to the project evaluation process by several computations and gives very well-structured guidance along with the evaluation process. Therefore, using both methodologies together will make the decision-making process more realistic and concrete.

It is important to state that the calculations made in this study do not determine the decision itself but guide the final decision. These mathematical methodologies help decision-makers make more realistic decisions by distancing their intuitive beliefs and judgements in business life. The methodologies applied in this study are just means of shaving the prejudices and subjective thoughts of decision-makers, restricting them from reaching a more sensible decision.

Eventually, this study proposed a mixed CBA and AHP methodology to make the decision makers make more realistic decisions about big projects like environmental and ergonomics programs, which can be seen as a pure expense at first. This methodology will help to convince the decision-making committee to approve the projects more easily. But, of course, the decision makers can make decisions contradictory to the results of calculations in the project management process. In other words, the methodologies applied in this study allow them to give strong structured guidance in decision-making processes of complex projects like ergonomics programs or environmental projects especially seen as a pure expense at first in business.

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Externally peer-reviewed

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