Evaluation of the Effects of a Center of Excellence Support Program on National Technology-Based Strategic Goals of a Country: A Case Study

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Abstract

In recent years, significant technological developments have been recorded in the Republic of Türkiye, especially in the field of the defense industry. Incentive and support policies have been developed and some strategic goals to be achieved have been determined in order to sustain these developments in the defense industry and other areas. Within this context, the National Scientific and Technological Research Council started a program in order to support the development of manufacturing technologies for the defense industry under the collaboration of leading defense industry companies and experienced universities on manufacturing processes. While the technical work within this research has important contributions to the economic and technical development in the country, it also has some effects on the national technology-based strategic goals of the country. In this study, the evaluation of the effects of the program on these targets is modeled as a multi-criteria decision-making problem. Benefits-Costs-Opportunities-Risks (BOCR) based Analytic Hierarchy Process (AHP) method is applied to evaluate the effects of the program on national technology-based strategic goals and the contribution of the program to each goal is calculated.

Keywords
Multi-criteria evaluation, manufacturing technologies, BOCR analysis, AHP

1. Introduction

Additive Manufacturing, which emerged in the 1980s through the work of Charles Hull, facilitates the efficient and cost-effective production of complex products with unique microstructures and material properties (Parsazadeh et al. 2023). This technology, also known by different terms such as 3D printing and layered manufacturing in the literature, is used in various industries to describe an additive process in which material is added layer by layer to create physical prototypes, product parts, or final products from digital data (Matos 2019).

Although additive manufacturing technology has been used primarily for prototype production worldwide for approximately 25 years, its use has increased significantly in recent years, particularly in the medical, automotive, aerospace, and space industries. The use of additive manufacturing technology in the manufacturing industry will not only reduce manufacturing costs and increase efficiency but also change the conventional supply chain structure and business models (The Economist 2018). Additive manufacturing is considered a more suitable technology for economically sustainable small and medium-volume productions without additional cost for design complexity. (EPMA 2019).

The aviation and aerospace industry, in which the study is situated, is constantly in need of innovation, and products are highly complex and produced in small numbers. Therefore, it is believed that additive manufacturing will provide significant advantages both in terms of cost and the environment (Ingarao and Priarone 2020). In recent years, significant progress has been made in the aviation and space industry in Türkiye. The implementation of the program initiated to support the development of manufacturing technologies in Türkiye will focus on the aviation and space industry as one of the key sectors. The importance of using additive manufacturing technology will be emphasized within the scope of support for priority products to be determined in the aviation and space industry. To sustain technological advancements, it is crucial to increase the local production of critical technologies and the use of local products in the manufacturing of aircraft, spacecraft, and related machinery. The research program initiated by the Ministry of Industry and Technology of the Republic of Türkiye aims to provide the country with the ability to design and produce technological products with strategic value. It is of great importance to measure the impact of additive manufacturing practices on Industry and Technology-based goals. This study proposes a BOCR-AHP-based approach to measure the impact of the research program carried out on the application of additive manufacturing technologies in the aerospace industry on the goals determined in the industry and technology strategy.

1.1 Objectives

This study aims to evaluate the social impact of additive manufacturing technology on Türkiye's technology-based goals. BOCR-AHP-based approach, which is one of the multi criteria decision-making techniques, is used to measure this effect.

2. Literature Review

In the literature, numerous approaches have been developed for examining the factors that affect strategic goals and decisions. In this context, multi criteria decision-making techniques are also widely used methods.

Chen et al. (2010) proposed an Analytic Network Process (ANP) model integrated with a Benefits, Opportunities, Costs, and Risks (BOCR) analysis for the selection of supportive management system projects and partners of power companies. Performance, goal-setting, and marketing needs criteria were identified as strategic criteria, and the Delphi technique was used to achieve expert consensus on the prioritization of strategic criteria and BOCR priorities based on strategic criteria. Kabak and Dağdeviren (2014) proposed a BOCR-ANP hybrid method for prioritizing renewable energy sources, which is an important strategic decision related to energy policies.

Simelyte et al. (2014) evaluated investment policy options that would benefit Lithuania's strategic goals by defining a decision problem with a two-level network by determining criteria and sub-criteria based on BOCR. Arsić et al. (2018) evaluated strategy options for national park management by combining the ANP and SWOT techniques.

Janeš et al. (2018) presented a comparative analysis of the Analytic Hierarchy Process (AHP) – BSC and ANP-BSC models to prioritize BSC strategic objectives. They classified the strategic objectives according to four perspectives (financial perspective, customer perspective, internal process perspective, learning and growth perspective) and created a strategic map of the objectives.

Wollmann and Tortato (2019) proposed an approach called Strategic Decision Making for Sustainability and Value Innovation to evaluate strategic decision alternatives based on sustainability, budget constraints, and value innovation criteria using the BOCR-ANP and mathematical modeling-based approach.

The use of additive manufacturing technology, which enables easier, cheaper, and customized production with less resource consumption, has rapidly increased and become widespread in measuring social impacts. The use of this new technology can have different effects in various fields. One of the most important effects is on factors that affect social life. Various studies have shown that these factors can create social impacts that affect people's health, social welfare, quality of life, and working conditions.

Ribeiro (2017) conducted a study to determine the social impacts of additive manufacturing technologies, which have been rarely studied, and to identify how these impacts affect which stakeholders and in what ways. Their study examined 11 key topics: education, trade, intellectual property, employment and labor structure, access to technology, economy, environment and energy consumption, supply chain, health and occupational hazards, security, and government approach.

Matos et al. (2019) conducted a case study to identify the social impacts of additive manufacturing technology on people's health, social welfare, quality of life, and working conditions, as well as the causes of these impacts. The research questions of the study aim to determine the main factors that may cause social impacts resulting from the use of additive manufacturing technology, identify the types of social impacts, and explain the cause-and-effect relationships between additive manufacturing factors and social impacts.

Naghshineh et al. (2020) proposed a framework to evaluate the social impacts of additive manufacturing products at different stages of their life cycle. Since different stakeholder categories are affected in each stage, stakeholders were structured into sub-categories to better identify the affected contexts. The developed model can be directly applied to case studies to evaluate the social impacts of products produced by additive manufacturing technology.

Naghshineh et al. (2021) presented the effects of additive manufacturing technologies on the social life cycle from the perspectives of five identified stakeholders: local communities, society, consumers, value chain, and workers. A comprehensive literature review was conducted during the application of the method.

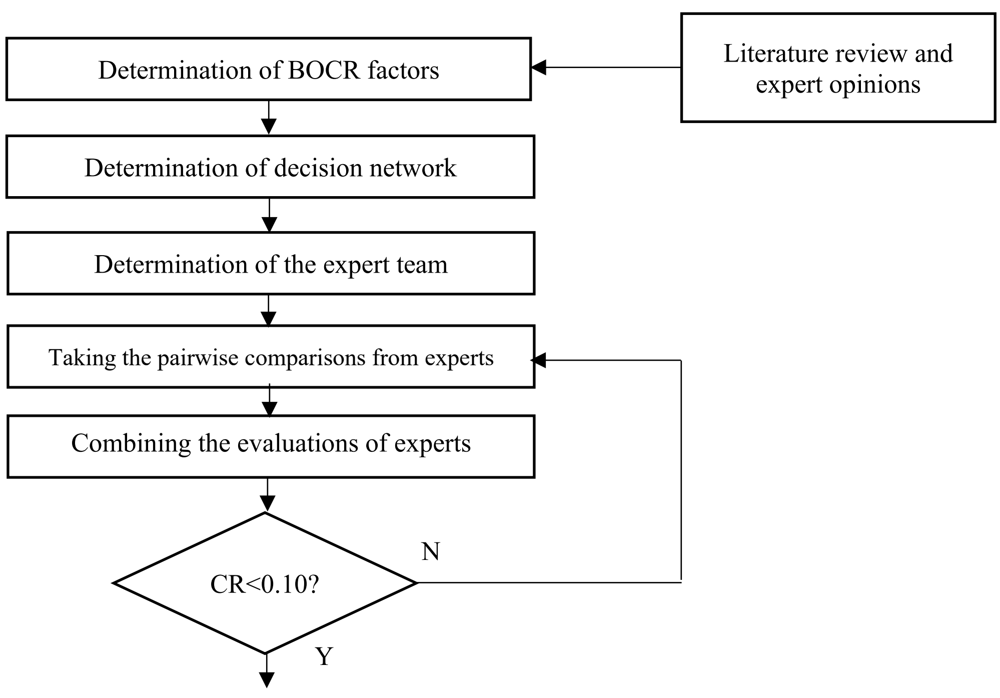
Bappy et al. (2022) utilized the AHP and ER (Evidential Reasoning) approaches to analyze the social impacts of additive manufacturing. The AHP method was used to weigh the characteristics related to social impacts which are the economic impact index, health, quality of life and safety impact index, and education and skills impact index.

Within the scope of the study, the social effects of additive manufacturing in the literature were investigated and the final impact factors were determined by collecting the opinions of the stakeholders in order to be integrated into this study.

3. Methods

This paper utilizes the Benefits, Opportunities, Costs and Risks (BOCR)- Analytic Hierarchy Process (AHP) integrated technique to analyze the effects of the research program on the national technology-based strategic goals of Türkiye.

The methodology followed is shown in Figure 1.



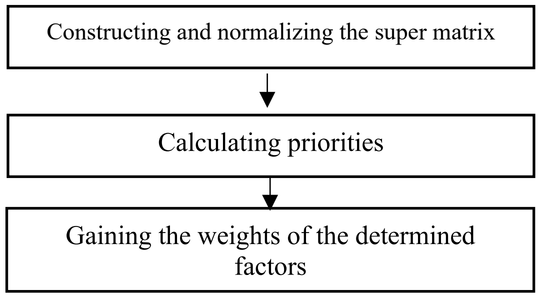


Figure 1. The representation of the methodology followed

The consistency ratio check is a critical step throughout the methodology; if the results are inconsistent, experts are asked to review their assessments. Figure 2 shows the general representation of the decision problem handled with AHP-based analysis.

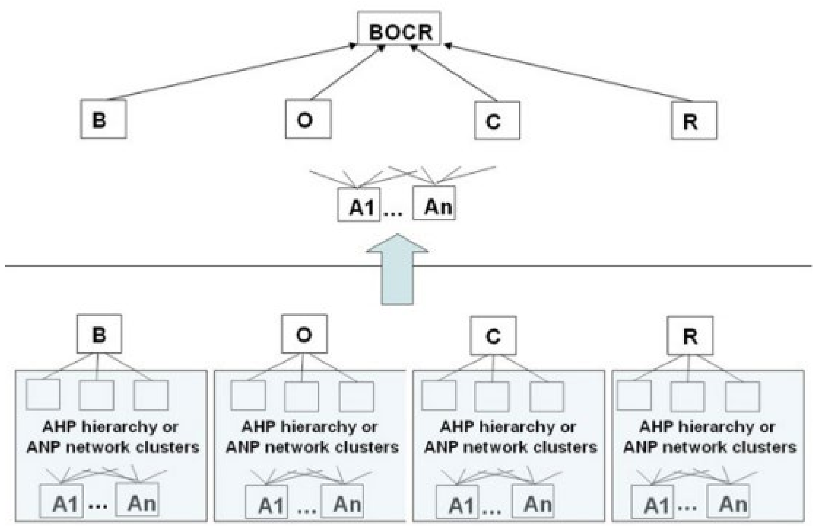


Figure 2. Structure of the decision problem handled with AHP-based BOCR analysis

In the analyzes where there are interactions between the factors taken into account in the evaluation, if similar analyzes have not been conducted before, it has been suggested as an appropriate way to evaluate the factors by grouping them in terms of benefits (Benefits), opportunities (Opportunities), costs (Costs) and risks (Risks) (Kabak and Dağdeviren, 2014).

Thanks to this approach, known as BOCR analysis, a holistic evaluation of the path options that can be followed, with their positive and negative aspects, is possible. In BOCR analysis, there are five different approaches proposed to reduce benefits, opportunities, costs, and risks to a single value (Wijnmalen 2007), (Lee et al. 2009), (Saaty and Özdemir 2003), (Saaty 2006).

These approaches are as follows:

Additive:

$$P_i = bB_i + oO_i + c(1/C_i)_{normalized} + r(1/\mathrm{R}_i)_{normalized}$$

Where,

B_i, O_i, C_i, and R_i values show the benefit, opportunity, cost and risk values for the decision option i, respectively; *b, o, c,* and *r* values express the weight values determined for benefit, opportunity, cost, and risk factors.

Probabilistic additive:

$$P_i = bB_i + oO_i + c(1 - C_i) + r(1 - R_i)$$

Subtractive:

$$P_i = bB_i + oO_i + cC_i - rR_i$$

Multiplicative priority powers:

$$P_i = B^b{}_i O^o{}_i [(1/C_i)_{normalized}]^c [(1/R_i)_{normalized}]^r$$

Multiplicative:

$$P_i = B_i O_i / C_i R_i$$

In this paper, the additive formulation was used in the BOCR analysis section.

The Analytical Network Process (AHP) method, developed by Saaty, is a decision-making technique in which the decision elements are defined with a hierarchical structure (Saaty 1977).

A decision is determined by applying the following steps in the BOCR-AHP method:

Step 1: Determination of expert group, criteria, sub-criteria, and criteria groups.
Step 2: Determination of BOCR criteria and hierarchy
Step 3: Construction of relationship matrix for BOCR criteria
Step 4: Construction of relationship matrix for criteria
Step 5: Calculation of priority values for BOCR criteria
Step 6: Calculation of final scores of decision alternatives based on BOCR criteria
Step 7: Making the decision

4. Data Collection

Based on an extensive literature review on the social impacts of additive manufacturing technologies, a list of effective criteria was primarily determined. These criteria were expressed as different dimensions of the social impacts of additive manufacturing technologies. By performing a number of meetings with stakeholders of the research program, some of the criteria were eliminated, due to their irrelevance with the scope of the program. During these meetings, stakeholders were asked to classify criteria into benefits (B), opportunities (O), costs (C), and risks (R) groups. As a result of these activities, 24 criteria were determined to be effective in the evaluation of the social impacts of the research program and 10 of these criteria were classified into benefits group, while 9 of them were identified to be opportunities, 3 of them were costs and 2 of them were risks. Evaluation criteria for the analysis are presented in Table 1.

Table 1. Evaluation criteria

Benefits	Opportunities	Costs	Risks
Perceived health, occupational hazards, and health risks (B1)	Employment structure (O1)	Reduction of demand for the workforce (C1)	Economic dependency or fragility (R1)
Circular economy (B2)	Market entry (O2)	Personnel protective equipment (C2)	Resistance to organizational change (R2)
Educational curricula (B3)	Supply chain reconfiguration (O3)	Modern infrastructure (C3)	
Participation in training (B4)	Technology transfer (O4)		
Automation (B5)	Increase in domestic production and decrease in export (O5)		
Sustainable production (B6)	Development of new skills (O6)		
Technology-oriented trained workforce (B7)	Disruption of the local economy (O7)		
Technology utilization in universities (B8)	Incentives for additive manufacturing training initiatives in the local community (O8)		
Product life extension (B9)	Education and training (O9)		
Environmental impact (B10)			

A group of experts from the stakeholders of the program and individual pairwise comparison matrices have been collected. Also, experts evaluated criteria along with their effect on the technology-based national goals of Türkiye within the perspective of the research program. Individual pairwise comparison was not presented in proceedings due to the page limitations, the aggregate score values of strategic goals and calculation results for criteria weights were provided in this paper. An aggregated score of criteria on goals is presented in Table 2.

Table 2. The aggregated score for strategic goals

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
B1	2.55	3.27	2.91	3.27	3.09	2.82	3.00	2.36	3.36	3.00	3.09	2.18
B2	5.73	5.55	7.00	6.73	5.64	5.36	6.27	5.00	6.18	6.00	6.36	5.73
B3	4.82	4.45	4.45	5.18	6.73	7.64	6.00	6.73	5.64	7.27	6.00	6.91
B4	4.55	4.64	4.09	4.82	6.64	6.82	6.27	6.91	5.82	7.27	6.36	6.18
B5	7.09	6.27	7.27	7.45	6.55	5.27	6.27	4.27	6.55	6.64	6.36	4.73
B6	7.45	6.55	8.36	8.64	5.82	4.73	6.00	4.73	6.64	6.18	5.55	4.64
B7	7.73	8.36	7.91	8.36	8.45	8.73	8.18	7.73	8.27	8.27	8.09	7.91
B8	6.18	7.00	6.00	6.09	8.09	8.55	7.91	7.82	6.91	8.00	7.45	7.36
B9	5.64	5.00	5.09	5.09	5.45	3.82	4.73	2.64	4.27	6.00	5.36	3.91
B10	4.64	3.64	3.91	4.09	4.91	4.18	5.09	2.73	3.73	4.55	4.91	4.27
O1	6.18	6.64	6.91	7.09	7.00	8.09	6.91	6.55	7.27	6.73	6.09	6.82
O2	6.82	5.64	6.64	6.55	7.27	5.82	7.09	5.00	6.82	7.36	6.64	6.00
O3	6.64	6.36	7.09	6.91	6.36	5.55	6.27	4.55	6.00	6.45	6.00	5.73
O4	8.09	7.27	7.64	8.09	7.82	7.55	8.91	6.55	7.27	8.18	7.91	7.18
O5	7.09	6.45	7.91	8.27	7.82	6.73	7.73	6.45	7.18	7.55	7.00	6.64
O6	7.45	7.55	8.45	8.64	7.82	8.09	8.45	7.55	8.27	8.45	8.36	7.82
O7	4.18	3.18	3.73	3.82	4.64	4.09	4.91	4.55	4.64	5.18	4.36	4.18
O8	6.09	5.91	5.91	6.36	7.00	7.45	6.91	6.64	5.91	6.45	6.36	6.36
O9	6.36	6.45	5.73	6.00	7.91	7.91	6.82	7.18	6.36	7.18	7.18	7.09
C1	5.09	4.64	5.55	5.82	5.36	5.09	5.27	5.27	5.27	4.45	4.64	4.27
C2	3.91	4.18	4.27	4.09	3.64	3.36	3.27	2.18	2.45	3.00	2.73	2.00
C3	6.64	6.36	7.73	8.36	7.82	6.55	8.36	5.36	7.82	8.18	8.18	6.45
R1	5.64	5.00	4.91	4.73	4.91	4.64	5.09	4.45	4.64	5.27	5.00	5.18
R2	5.27	5.45	5.55	5.45	4.73	5.82	5.00	4.36	5.36	5.09	5.00	5.82

The strategic goals given in Table 2 and shown between A1 and A12 are explained as follows:
A1. The 5-year average of the manufacturing industry in Gross Domestic Product (GDP) is targeted to be 20% and to reach 21% in 2023.

A2. It is aimed that the added value produced by the industry per worker in the industry will be 35,000 USD.

A3. It is aimed to increase the manufacturing industry exports to 210 billion USD in 2023.

A4. It is aimed to increase the share of medium-high and high technology products in manufacturing industry exports to 44.2% and 5.8%, respectively, by 2023.

A5. It is aimed to increase the ratio of R&D expenditures in GDP to 1.8% in 2023.

A6. In Turkey, it is aimed to increase the R&D human resources to 300 thousand FTE and the number of researchers to 200 thousand by 2023.

A7. By 2023, it is aimed that 23 companies from Turkey will be among the 2,500 companies that spend the most on R&D in the world.

A8. It is aimed that the number of professional software developers in Turkey will exceed 500 thousand by 2023.

A9. By 2023, it is aimed that the annual investment size in technology-based initiatives in Turkey will reach 5 billion Turkish Liras.

A10. It is aimed to produce at least 23 smart products with a world-leading market share or brand value in at least one of Turkey's disruptive technology areas.

A11. The number of Turcorn - Turkish technology startups with a valuation of USD 1 billion is targeted to be at least 10 by 2023.

A12. It is aimed to design new mechanisms and structures, with the Ministry of Industry and Technology as the first interlocutor, to increase efficiency by revising processes, in order to provide support and service from a single point with a "stakeholder-oriented" approach to industrialists, suppliers, entrepreneurs, research infrastructures and universities in industry and technology issues.

The pairwise comparisons were used to calculate BOCR criteria weights, and these values were used to aggregate the score of each strategic goal in view of criteria into a single value.

5. Results and Discussion

The decision network of the problem was modeled in Superdecisions software (Creative Decisions Foundation, 2023). Individual pairwise comparison matrices collected from 12 experts were integrated by using the geometric mean operator. Integrated values were written to the model created in Superdecisions software and criteria weights were obtained as given in Table 3.

Table 3. Criteria weights

BOCR Sets	Importance Degree	Criteria	Local Weights	Criteria Weights
Benefits	0.307	B1	0.045	0.014
		B2	0.062	0.019
		B3	0.097	0.030
		B4	0.081	0.025
		B5	0.080	0.025

BOCR Sets	Importance Degree	Criteria	Local Weights	Criteria Weights
		B6	0.079	0.024
		B7	0.238	0.073
		B8	0.175	0.054
		B9	0.064	0.020
		B10	0.079	0.024
Opportunities	0.464	O1	0.064	0.030
		O2	0.071	0.033
		O3	0.065	0.030
		O4	0.146	0.068
		O5	0.133	0.062
		O6	0.187	0.087
		O7	0.052	0.024
		O8	0.137	0.063
		O9	0.147	0.068
Costs	0.133	C1	0.215	0.029
		C2	0.165	0.022
		C3	0.620	0.083
Risks	0.096	R1	0.550	0.053
		R2	0.450	0.043

It can be seen that the most important criterion in the evaluation of the research program is O6 (development of new skills). It has been followed by C3 (modern infrastructure) and B7 (technology-oriented trained workforce). B1 (perceived health, occupational hazards, and health risks) is seen to be the least important factor among 24 criteria taken into account within the analysis. A graphical representation of the criteria weights is also given in Figure 3.

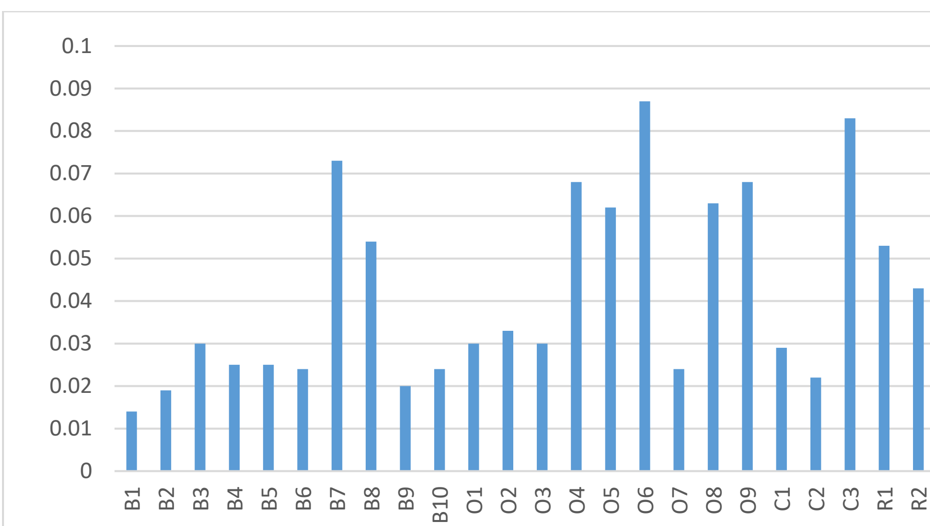


Figure 3. Graphical representation of criteria weights

Criteria weights were used to aggregate score values of strategic goals with respect to criteria. Based on the BOCR – AHP analysis, aggregated score of each strategic goal was calculated as they are presented in Table 4.

Table 4. The aggregated score of strategic goals

Strategic Goal	A1	A2	A3	A4	A5	A6
Score	5.09	4.95	5.16	5.37	5.57	5.45
Strategic Goal	A7	A8	A9	A10	A11	A12
Score	5.55	4.90	5.20	5.60	5.33	5.07

Based on the aggregated score values, it can be concluded that the research program contributes to the 10th strategic goal of Türkiye (having at least 23 smart products with world-leading market share or brand value in at least one of the disruptive technology areas) most. The ranking of strategic goals found as:

A10 >> A5 >> A7 >> A6 >> A4 >> A11 >> A9 >> A3 >> A1 >> A12 >> A2 >> A8

6. Conclusion

In this study, BOCR – AHP analysis is made to evaluate the effects of a research program supported by the Scientific and Technological Research Council of Türkiye on Türkiye's technology-based national strategic goals. Within the research program, it is aimed to develop additive manufacturing technologies in the aviation and space industry. To measure the effects of the program on national strategic goals, a literature review was conducted to determine the social effects of additive manufacturing technologies. Then, a series of meetings was performed with program stakeholders to collect their opinions about the program's effect on the national strategic goals and criteria evaluation. Collected data were used to calculate the importance degree of evaluation criteria and the contribution of each goal was calculated by the additive formula of BOCR analysis.

The social effects of additive manufacturing may have some interactions. Not taking this issue into account can be seen as the main limitation of this study. For this reason, an ANP-based BOCR analysis will be conducted in further studies. Moreover, the utilization of linguistic terms for the evaluation of criteria and goals can be modeled by using fuzzy methodologies in further studies.

References

Arsić, S., Nikolić, D., Mihajlović, I., Fedajev, A., & Živković, Ž. A new approach within ANP-SWOT framework for prioritization of ecosystem management and case study of National Park Djerdap, Serbia, *Ecological Economics*, vol. 146, pp. 85-95, 2018.

Bappy, M. M., Key, J., Hossain, N. U. I., & Jaradat, R. Assessing the Social Impacts of Additive Manufacturing Using Hierarchical Evidential Reasoning Approach, *Global Journal of Flexible Systems Management*, vol. 23, no. 2, pp. 201-220, 2022.

Chen, H. H., Lee, A. H., & Kang, H. Y. A model for strategic selection of feeder management systems: A case study, *International Journal of Electrical Power & Energy Systems*, vol. 32, no. 5, pp. 421-427, 2010.

Creative Decisions Foundation, Superdecisions, 2023. Available: https://superdecisions.com/. Access date: 03.02.2023.

European Powder Metallurgy Association [EPMA], Introduction To Additive Manufacturing Technology: A guide for Designers and Engineers, 2019, Available:https://www.epma.com/epma-free-publications/product/introduction-to-additive-manufacturing-brochure, Accessed on September 14, 2021.

Ingarao, G., & Priarone, P. C. A comparative assessment of energy demand and life cycle costs for additive- and subtractive-based manufacturing approaches, *Journal of Manufacturing Processes*, vol. 56, pp. 1219–1229., 2020.

Janeš, A., Kadoić, N., & Begičević Ređep, N. Differences in prioritization of the BSC's strategic goals using AHP and ANP methods, *Journal of information and organizational sciences*, vol. 42, no. 2, pp. 193-217, 2018.

Kabak, M., & Dağdeviren, M. Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology, *Energy conversion and management*, vol. 79, pp. 25-33, 2014.

Lee, A.H.I., Chen, H.H., Kang, H.Y., Multi-criteria decision making on strategic selection of wind farms, Renewable Energy, vol. 34, pp. 120-126, 2009.
Matos, F., Godina, R., Jacinto, C., Carvalho, H., Ribeiro, I., & Peças, P. Additive manufacturing: Exploring the social changes and impacts, *Sustainability*, vol. 11, no. 14, pp. 3757, 2019.
Naghshineh, B., Lourenço, F., Godina, R., Jacinto, C., & Carvalho, H. A social life cycle assessment framework for additive manufacturing products, *Applied Sciences*, vol. 10, no. 13, pp. 4459, 2020.
Naghshineh, B., Ribeiro, A., Jacinto, C., & Carvalho, H. Social impacts of additive manufacturing: A stakeholder-driven framework, *Technological Forecasting and Social Change*, vol. 164, pp. 120368, 2021.
Parsazadeh, M., Sharma, S., & Dahotre, N. Towards the Next Generation of Machine Learning Models in Additive Manufacturing: A Review of Process Dependent Material Evolution, *Progress in Materials Science,* pp. 101102, 2023.
Ravi, V., Shankar, R., Tiwari, M. K., Analyzing Alternatives in Reverse Logistics for end-of-life computers: ANP and Balanced Scorecard Approach, Computers and Industrial Engineering, vol. 48, no 2, pp. 327-356, 2005.
Ribeiro, A. Additive Manufacturing Social Impacts: A Conceptual Model, *Master's Thesis, Nova University of Lisbon, Lisbon, Portugal,* 2017.
Saaty, T. The Analytic Hierarchy Process (AHP) for Decision Making. In Proceedings of the Kobe, Kobe, Japan, 21–22 November 1980, pp. 1–69, 1980.
Šimelytė, A., Peleckis, K., & Korsakienė, R. Analytical network process based on BOCR analysis as an approach for designing a foreign direct investment policy, *Journal of Business Economics and Management*, vol. 15, no. 5, pp. 833-852, 2014.
The Economist, adding it up: The economic impact of additive manufacturing is an Economist Intelligence Unit report, sponsored by The Munich Technology Conference, 2018. Available: https://eiuperspectives.economist.com/sites/default/files/Addingitup_WebVersion.pdf, Accessed on August 30, 2021.
Wijnmalen, D. J., Analysis of benefits, opportunities, costs, and risks (BOCR) with the AHP–ANP: A critical validation. Mathematical and computer modelling, vol. 46, no. 7-8, pp. 892-905, 2007.
Wollmann, D., & Tortato, U. Proposal for a model to hierarchize strategic decisions according to criteria of value innovation, sustainability and budgetary constraint, *Journal of cleaner production*, vol. 231, pp. 278-289, 2019.

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