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Research Paper

CO-Active Neuro- Fuzzy Inference System Application in Supply Chain Sustainability Assessment Based on Economic, Social, Environmental, and Governance Pillars

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Abstract

The main aim of this study is proposing an assessment model for evaluating the supply chain sustainability across the automotive sector. In this study, through reviewing the sustainability indicators in the economic, social, environmental, and governance pillars, the fuzzy Delphi is applied. Then, survey method is used to implement the model designed in CANFIS to evaluate the sustainability indicators. In this research, the proposed model was used for evaluating the sustainability in four pillars which is more inclusive than previous research. To improve the sustainability, it must be evaluated and measured so that after the improvement measures, the results are determined through measurement. According to the findings, it was concluded that the model designed in CANFIS was a reliable tool for assessing the sustainability.

Keywords *Supply Chain Management; Sustainability Assessment; CANFIS Fuzzy Inference System; Fuzzy Delphi; Automotive Industry*

Introduction

In the present era of globalization and the resulting development of virgin areas, the procurement of demands is the most vital and busiest activity; one

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that places SC at a position further than the economical discussions and aspects, overriding such issues as maintaining equitable work conditions, producing environmentally friendly products, etc. Consequently, supply chain management has turned into one of the serious concerns for many enterprises of all sizes and across a widespread spectrum of industries (Seuring, 2013). It can be said that supply chain management now is a strategic administrative tool for the company pursuing its missions in terms of economic competitiveness, delivering timely and of superior quality products and services at an accelerated industrial cycle (Ghadikolae & Gholamrezatabar, 2014). This is however, dependent to the improvement of both company itself and the SC performance (Fritz et al., 2017). The Sustainable environmental and social standards throughout the supply chain ensure companies to achieve at least stable performance (Seuring, 2013). Due to growing awareness of communities regarding the environment and sustainability around the world, organizations cannot ignore sustainability priority in the business. To achieve higher business performance and competitive edge, the selection of sustainable suppliers constitutes an important decision making problem in the industrial SC management. Sustainability-focused SC is concerned with the expansion of green supply chain, where the social metric along with the economic and green metrics are evaluated from the SC context perspective. The inclusion of environmental, economic, and social dimensions to ensure sustainable development has been the most important strategic task the businesses and organizations are dealing with throughout the recent years. Suppliers can play an important role in implementing the SC plans and achieving social, environmental, and economic goals (Luthra, 2017). Companies inevitably have facilitated their performance from economic accountability to shareholders to sustainable performance for all the stakeholders. Sustainability in its most updated meaning worldwide involves

a process comprising the product design and post-consumer product management, as well as many complementary procedures in between (Fritz et al., 2017). Establishment of SSCM for example, can give aid ensuring long-time environmental, social and economic benefits for both the leather manufacturers and customers. Moreover, SSCM procedures can integrate environmental, social and SC management methods aimed at prevention or minimization of environmental degradation as well as enhancing the socio-economic sustainability (Abdul Moktadir et al., 2018). In this environment, information systems are gaining an increase in roles and abilities to support knowledge-intensive work and thereby becoming a critical factor for companies to sustain and enhance competitiveness (Bigdeli et al,2019).During the past decades, an ever-increasing number of stakeholders have been added to the sustainable development process beneficiaries. Given the lack of 'governance' and 'stakeholder' role in the SC sustainability in the previous literature, we tried to examine the SC sustainability in four economic, environmental, social and governance dimensions. After extensive literature review, the SC sustainability indices were extracted across the above four dimensions. Then, the fuzzy Delphi technique and conceptual model were applied and the expert consensus was acquired.The automotive industry, as an old and important industry that accounts for a large share of the country's GDP, in all parts of its life cycle, from the exploitation of natural resources to the manufacture, production, consumption and then direct and indirect consumption. . Due to the increasing pressures and regulations of state and non-governmental organizations and consumer demand, car manufacturers around the world are reinforcing their sustainable management. Therefore, the managers of the automotive supply chain should consider their decisions in addition to current costs, environmental aspects and social costs (Alahyari &

Pilevari, 2019). How to design a model of SC sustainability assessment using CANFIS in the automotive sector?

Literature Review

Supply chain management is a support term that captures both operational and strategic functions to meet the demands of customers. Operational activities include routine sourcing, conversion, production, and logistics, while strategic functions focus on coordination, collaboration, and integration of key functions and processes inside and across companies Lawrence et al (2020) .Mengfeng et al. (2019) investigated the role of customer awareness (as a stakeholder) on the sustainability performance. Abdul Moktadir et al. (2018) in their study determined the barriers and examined the causal relationship among them for facilitating the efficient implementation of SSCM in the Bangladesh leather production industry. Mathivathanan et al. (2018) provided a basis for industrial executive managers to realize the inter-influences among the methods and practices, and increased the potential for successful implementation of SSCM approach across the automotive industry. In a paper issued by Fu Jia et al. (2018), specified the gaps in need of further research by the scholars on the topic, especially taking into account the developing countries. Zhang et al. (2018) proposed a hierarchical structure of supply chain management, and proposed a multi-item measurement scale to represent the particular management practices of sustainable SC management. In a study undertaken by Qorri et al. (2018) a better understanding of how the existing approaches evaluate the sustainability of SC is given and provides new insights into sustainability performance management methods, SC configuration and selection of metrics. Rajeev et al. (2017) in their research investigated the evolution of sustainability issues through analyzing the trends across industries, economies

and various methodologies. In a study conducted by Ghadimi et al. (2017) a practical decision making approach for evaluating and selecting the most sustainable suppliers for an automotive spare parts manufacturer licensed under a France-based automotive company was proposed. Fritz et al. (2017) emphasized their need for defining precisely which sustainability dimensions could be found in the various aspects of sustainability and showed the eight relevant sustainability dimensions. Arushanyan et al. (2017) proposed a sustainability assessment framework for evaluating the environmental and social risk as well as the opportunities of future scenarios and provided guidelines for its application. Su et al. (2016) introduced a hierarchical grey decision-making trial and assessment laboratory method to identify and analyze criteria and alternatives in incompatible information. Reefke and Sundaram (2016) in their study confirmed, questioned and extended the knowledge on sustainable SC management. The identified themes were integral for the management and performance of sustainable SC. Findings of a research conducted by Winter and Lasch (2016) contributed to the research literature about sustainable SC management, maintaining empirical insights on the application and significance of environmental and social criteria in supplier assessment. Luthra et al. (2016) proposed a framework for evaluating sustainable supplier selection through the use of an integrated (AHP), (VIKOR), a multi-criteria optimization and the compromise solution approach. This study primarily identified 22 sustainable supplier selection criteria and three dimensions of criteria (economic, environmental and social) through literature review and experts' opinions. Esfahbodi et al., (2016) in their study developed an empirically evaluated an integrated SSCM performance framework supported by the Resource Dependence Theory (RDT), linking SSCM practices and their relations with organizational performance. Wilhlm et al. (2016) in a study employed the agency and

institutional theory to examine the conditions in which first-tier suppliers would act as agents who satisfy the lead firm's sustainability requirements (i.e., the primary agency role) and would apply such requirements in their suppliers' operations (i.e., the secondary agency role). Feedback between supply chain and stability is the next phase of the operation and the environment. Members of the Europe Union formed a group that aimed to implement and enforce Law that makes manufacturers responsible for collecting, recycling and safe disposal of their waste (Shahriari et al,2016). Gualandris et al. (2015) in another study synthesized a model that could propose how firms might deal with the accountability for sustainability affairs in their SC. Turker and Altuntas (2014) attempted to fill this gap conceptually through mapping the present status of the sustainable SC management (SSCM) in the fashion industry through analyzing reports from nine companies that used the same reporting guidelines. Chaedine-Baumann and Botta-Genoulaz (2014) introduced an outline for sustainable performance characterization and an analytical model of sustainable performance evaluation. The mentioned framework was used to characterize a company's sustainable performance in the economical, environmental and social domains. Varsei et al. (2014) in a paper tried to propose a framework capable of assisting focal companies in the establishment of sustainable SC. In this study, the sustainable development from an industrial viewpoint was extended beyond organizational boundaries to integrate a SC approach. Seuring (2013) provided a summary of the researches performed on quantitative models for forward SC and thereby contributed to greater substantiation of the discipline. Amindoust et al. (2012) in their work determined the sustainable supplier selection criteria and sub-criteria and accordingly proposed a methodology for the assessment and ranking of a certain group of suppliers. Zailani et al. (2012) in their work reported that the environmental procurement produced a positive

influence on economical, social and operational categories' results, while sustainable packing had a positive effect on environmental, economic and social outcomes. The findings empirically proved that SSCM process had a positive influence on the sustainable SC performance, especially from the economic and social angles.

Research Methodology

In the present study, the author uses three documentary, Delphi and survey methods. Data collection required for the theoretical bases and forming a conceptual model of library document method as well as reviewing the latest scientific publications on the sustainable SC management, all were also used to refine and confirm the extracted indicators of the study to design the conceptual model Fuzzy Delphi. Due to the large volume of fuzzy Delphi calculations and the fact that the main method of model design is CANFIS, the reader is advised to refer to the source published by the authors of this article (Alahyari & Pilevari, 2018). Finally, in the last step, the survey method was used to implement the model designed in CANFIS with the aid from a questionnaire to evaluate the sustainability factors (dimensions and indicators according to Figure (1) and Table (2)) in the case study, as well as in validation. The model was performed using error calculation. Since this research is not an attitude assessment, there is no need for generalization of results to the whole society (N). In fact, the limitation of accessibility to experts determines the statistical population. For further clarification, the statistical population of this research in the process of extracting the conceptual model, validating as well as designing a network-based adaptive fuzzy inference system included 20 academics and experts.For the practical implementation of the model in the under study organization and the completion of the final questionnaire, the experts of Iran Khodroo Industrial

Group were asked to participate in this study.Neuro-Fuzzy Inference system is an important tool in applying Expert knowledge. In the absence of complete and accurate information about the phenomenon under study, this system analyzes and predicts the behavioral pattern of the phenomena based on fuzzy logic and design. According to fuzzy logic, based on the limited and inaccurate information that exists from a phenomenon, we will be able to identify and predict the relationships between variables. Therefore, in this study, due to the lack of accurate information on supply chain stability, Neuro-fuzzy inference systems have been used to evaluate it. Neuro-fuzzy inference systems have a knowledge-based structure that can model human knowledge without the use of precise quantitative analysis. In the present study, due to the following conditions, a network-based adaptive Neuro-fuzzy inference system can be used for modeling.

- Among the features of this algorithm, we can mention the possibility of using hard and soft data at the same time and the possibility of aggregating the opinions of experts and the rules derived from historical data.
- Effective methods are usually used in updating membership functions, while in Neuro-fuzzy inference system these values are constant.

In this research, data taken from the knowledge of experts are used in designing the CANFIS model. Questionnaires with random values and different variables were used to collect experts' knowledge. For example, to design the CANFIS model, experts are asked to express their real experiences or their scientific knowledge about the output variable according to different values of economic, social, environmental and governance indicators. In this regard, oral questionnaires (a kind of interview) with input and output variables in the range of zero to ten (0-10) have been used, which works to extract the knowledge of experts in a more structured way. It is noteworthy

that in this paper, the post-diffusion method is used to teach the network-based CANFIS adaptive system.

Figure 1

Proposed Conceptual Model of Research

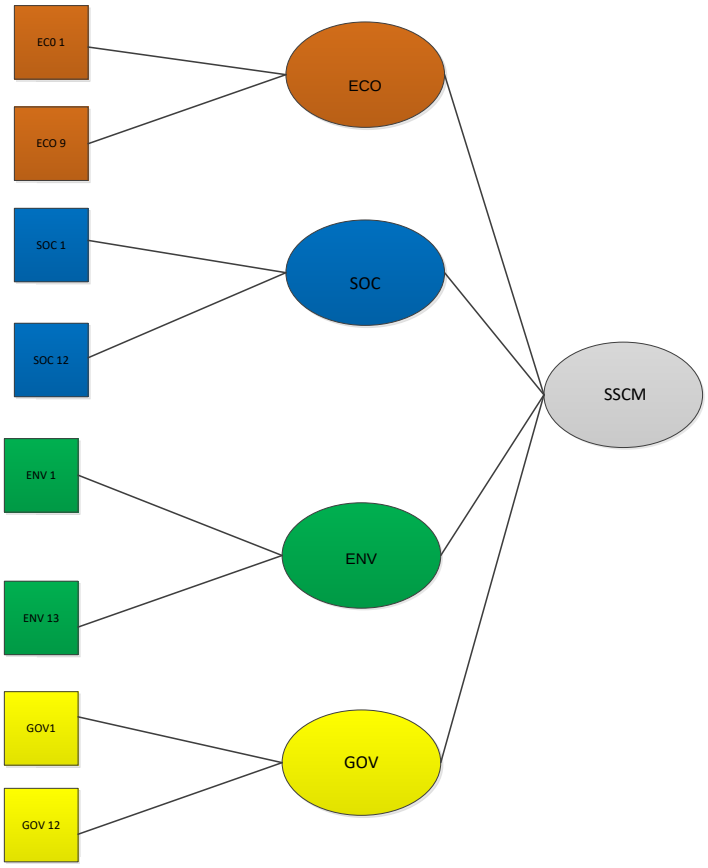


Table 1
Supply Chain Sustainability Pillars, Indicators, and Related Code

Row	Pillars	Indicators Code	Indicators	Reference
1	Economic	ECO 1	Financial performance and market share	Khatami Firouz Abadi et al.(2015), Olfat, & Mazrooii Nasr Abadi (2014).
2		ECO 2	Amount of income from green products	Khatami Firouz Abadi et al (2015), Olfat, & Mazrooii Nasr Abadi (2014).
3		ECO 3	Product quality and safety	Khatami Firouz Abadi et al (2015), Qorri et al (2018)
4		ECO 4	Timely delivery of goods and services	Khatami Firouz Abadi et al (2015), Qorri et al (2018)
5		ECO 5	Brand management, brand reputation	Sadeghi Moghadam et al (2015), Ghadimi et al (2017)
6		ECO 6	Economic crisis management	Sadeghi Moghadam et al (2015)
7		ECO 7	Fight against corruption, money laundering, bribery	Sadeghi Moghadam et al (2015)
8		ECO 8	Revenue from recycling	Olfat, & Mazrooii Nasr Abadi (2014).
9		ECO 9	Resource Productivity	Olfat, & Mazrooii Nasr Abadi (2014), Qorri et al (2018)
10	Social	SOC 1	Amount of trained staff	Khatami Firouz Abadi et al.(2015), Olfat, & Mazrooii Nasr Abadi (2014).
11		SOC 2	Recruitment of local forces	Sadeghi Moghadam et al (2015)
12		SOC 3	Employing local suppliers	Sadeghi Moghadam et al (2015)
13		SOC 4	Entrepreneurial culture and entrepreneurship support	Sadeghi Moghadam et al (2015)
14		SOC 5	Improving infrastructure and community health	Sadeghi Moghadam et al (2015)
15		SOC 6	Support educational and charitable and non-profit institutions	Sadeghi Moghadam et al (2015)

Row	Pillars	Indicators Code	Indicators	Reference
16		SOC 7	Employee management with emphasis on employee social welfare	Sadeghi Moghadam et al (2015)
17		SOC 8	Non-Discrimination in Employment (Employment of Persons with Disabilities and Gender Non-Discrimination)	Khatami Firouz Abadi et al (2015), Sadeghi Moghadam et al (2015)
18		SOC 9	Ethics	Fritz et al (2017)
19		SOC 10	Occupational Health and Safety	Fritz et al (2017)
20		SOC 11	Customer Satisfaction	Sadeghi Moghadam et al (2015)
21		SOC 12	Transparency information	Luthra et al (2016)
22		ENV1	The rate of use of non-renewable energy	Khatami Firouz Abadi et al.(2015), Olfat, & Mazrooii Nasr Abadi (2014), Sadeghi Moghadam et al (2015)
23		ENV2	The destructive effects of the organization's services and products on the environment	Sadeghi Moghadam et al (2015)
24	Environmental	ENV3	Not taking into account environmental factors in investments	Sadeghi Moghadam et al (2015)
25		ENV4	Sue management in water, paper, energy consumption	Fritz et al (2017), Qorri et al (2018)
26		ENV5	Lack of waste and waste management	Sadeghi Moghadam et al (2015)
27		ENV6	Lack of energy management in the transportation and replacement of telecommunications technology	Sadeghi Moghadam et al (2015)

Row	Pillars	Indicators Code	Indicators	Reference
28		ENV7	The amount of waste generated	Olfat, & Mazrooii Nasr Abadi (2014), Varesi et al (2014)
29		ENV8	The amount of noise pollution	Olfat, & Mazrooii Nasr Abadi (2014)
30		ENV9	Greenhouse gas emissions	Rajeev et al (2017), Varesi et al (2014)
31		ENV10	Use of environmentally friendly raw materials	Winter et al (2016)
32		ENV11	Use of dangerous and toxic substances	Varesi et al (2014)
33		ENV12	The amount of air pollution	Qorri et al (2018)
34		ENV13	Lack of effective use of byproducts	Mathivathanan et al (2018)
35		GOV 1	Engage and engage with stakeholders	Fritz et al (2017), Sadeghi Moghadam et al (2015)
36		GOV 2	Create value for shareholders and stakeholders	Sadeghi Moghadam et al (2015)
37		GOV 3	Partner with lawmakers and impartial political assistance	Sadeghi Moghadam et al (2015)
38	Governance	GOV 4	Corporate Governance Principles and Compliance with Laws	Fritz et al (2017), Sadeghi Moghadam et al (2015)
39		GOV 5	Business values and ethics	Sadeghi Moghadam et al (2015)
40		GOV 6	Diversity of suppliers and relationships based on transparency, impartiality and integrity with suppliers	Sadeghi Moghadam et al (2015)
41		GOV 7	Evaluate suppliers' performance based on principles and policies	Sadeghi Moghadam et al (2015)

Row	Pillars	Indicators Code	Indicators	Reference
42		GOV 8	Having management systems	Fritz et al (2017)
43		GOV 9	Determine responsibility and power to achieve goals	Fritz et al (2017)
44		GOV 10	Research and Development	Fritz et al (2017)
45		GOV 11	Senior Management Commitment	Mathivathanan et al (2018)
46		GOV 12	Having long-term relationships with suppliers	Mathivathanan et al (2018)

Neuro-fuzzy hybrid systems integrate the fuzzy systems' advantages that consider the explicit, explainable and understandable knowledge on the one hand, and neural networks which deal with implicit knowledge acquired through learning on the other hand. Neural network learning suggests a superior way of regulating the expert's knowledge and automatically generates additional fuzzy rules as well as membership functions to satisfy specific characteristics, meanwhile saving the design time and costs. The basic component of CANFIS is fuzzy axon that applies membership functions to the inputs. The output of a fuzzy axon can be calculated using the below formula:

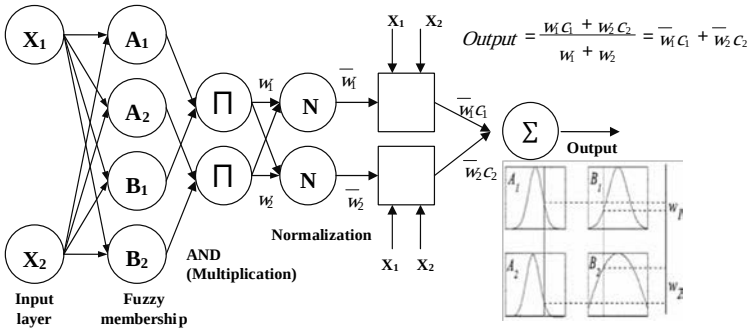
$$f_j(x,w) = \min \forall i(MF(xi,wij)), \quad (1)$$

where i =input index, j =output index, xi =input i, wij =weights (MF parameters) corresponding to the jth MF of input i and MF denoting membership function of the particular subclass of the fuzzy axon.This system can be considered as a special three-layer feed forward neural network. The first layer stands for the input variables, the middle (hidden) layer represents fuzzy rules and the third layer denotes the output variables. Fig. (2) illustrates

the CANFIS architecture applied in the present study (Saemi & Ahmadi, 2008).

Figure 2

The CANFIS Architecture Used in this Study



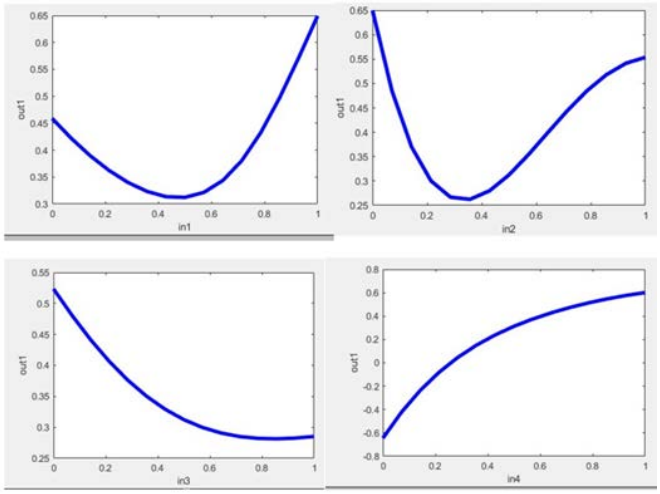
Finding

To answer the questions raised in this paper, after review studies, data collection and using fuzzy Delphi technique, a conceptual model was presented in four economic, social and environmental dimensions. In the economic dimension, four indicators: financial performance and market share, quality and safety product, timely delivery of goods and services and brand management were accepted as important indicators. Therefore, to sustain the SC, companies must take measures related to each indicator to improve. For example, for financial performance index and market share, it is necessary to strengthen the ability of supplying products at reasonable prices to gain more profit by obtaining more market share. Distance, the amount of waste generated the use of raw materials harmful to the environment and the amount of air pollution are considered as the most important indicators (because

environmental indicators are selected in a way that reduce sustainability in the model). In the social dimension, there are four indicators. The title of important indicators agreed upon by the experts include: the number of trained staff, professional ethics, occupational health and safety and customer satisfaction, creating value for the shareholders and stakeholders, principles of corporate governance and compliance with laws, having management systems and determining experts, assuming responsibility and power to achieve the goals. In designing the CANFIS system designed in this research, the optimal training method, i.e. the same hybrid method was used. Error Tolerance was applied to determine a criterion for ceasing training that is directly related to the size of the error. CANFIS designed with 100 training courses (EPOCH) achieved an acceptable error rate.The following diagrams (figure 3) show the effect of changes in economic, social, environmental and governance dimensions (first to fourth inputs) as inputs to the inference system designed to assess the SC sustainability. In the economic dimension as the first input, the distance 0 to 0.4 shows a decreasing trend and from 0.5 to one shows an increasing trend and at the distance 1 it reaches maximum sustainability. In the social dimension as the second input, the distance 0 to 0.3 shows a decreasing trend and from 0.4 to 1, increasing trend. In the environmental dimension as the third input, it is a completely decreasing trend. Environmental indicators that were considered negative show their role in reducing sustainability. In the governance dimension as the fourth input, the trend of sustainability changes is incremental.

Figure 3

Diagram of the Impact of Sustainability Dimensions on Uustainability



In the present study, the root mean square error (RMSE) has been considered as a criterion for model validation (figure 4). Validation was performed using test data to examine the ability to generalize the obtained fuzzy inference system. Test data is a collection of data that has not yet been involved in the model training process. This is done to check the accuracy of the designed CANFIS performance. For example, in CANFIS designed to evaluate SC sustainability, comparisons are made between output and test data (figure 5), and RMSE and MSE errors are calculated, which are acceptable values. Then CANFIS system was designed and via implementation of the studied data error, the MSE = 0.0098 while the coefficient of determination was R2 = 0.8954 (table 2).

Figure 4

Error Chart Created in 100 CANFIS Training Courses for SC Sustainability

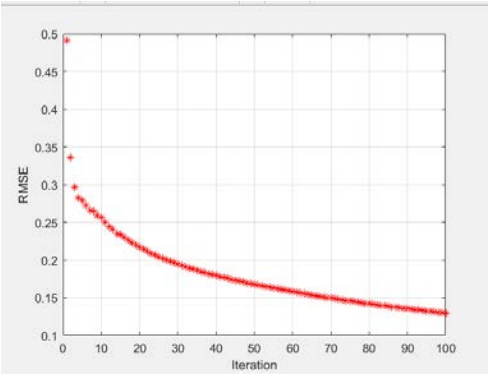


Figure 5

Comparison of Output Data and Test Data Pertaining to the Implementation of CANFIS Sustainability

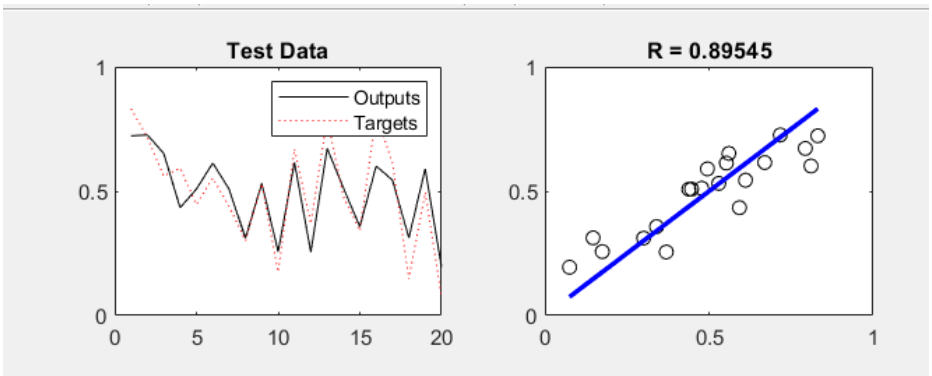


Table 2

Results of the Implementation of the CANFIS Model of Supply Chain Sustainability

MSE	0.0098
RMSE	0.0990
MPE	0.0826
MAE	0.1995
R^2	0.8954

In this test, the input variables of each CANFIS are changed in different modes (very high and very low) and the sensitivity of the model to these changes is investigated. For example, if we consider CANFIS designed to evaluate sustainability, which has four inputs (economic, social, environmental and governance) and its output also indicates sustainability, as shown in Table (3), the model against changes in variable inputs from very low (zero) to very high provides perfectly reasonable behavior.

Table 3

The Effect of Simultaneous Changes in Economic, Social, Environmental and Governance Dimensions on Sustainability

CANFIS Outputs	**CANFIS Inputs**			
sustainability	Economic	Social	Environmental	Governance
0.1	0	0	0	0
0.3	0.5	0.5	0.5	0.5
0.579	1	1	1	1

Conclusion

Paying attention to sustainability issues can improve the position of companies. Therefore, companies can prepare a written plan for managing their SC and consider these dimensions in the mission of their organization.

To improve the situation, sustainability must first be evaluated and measured so that after the adoption of improvement measures, the results can be determined via measurement. According to the findings of this study, it can be concluded that the model designed in CANFIS provides a reliable tool for assessing sustainability.Depending on the extent to which each dimension affects the sustainability, the importance of the dimensions has been investigated by sensitivity analysis. For this purpose, in the implementation of the CANFIS model, a fixed value is added to one of the inputs each time and the other values are kept constant until —according to table 4— an increase in the social dimension has the most impact and the increase in environmental dimension attains the least impact.

Table 4

Sensitivity Analysis of Stability Dimensions

No	GOV	ENV	SOC	ECO	SUSTAINABLE
1	0.5	0.5	0.5	0.5	0.3
2	0.5	0.5	0.5	0.8	0.486
3	0.5	0.5	0.8	0.5	0.55
4	0.5	0.8	0.5	0.5	0.327
5	0.8	0.5	0.5	0.5	0.484

This analysis helps in examining the effect of dimensions on sustainability, to achieve the ability to increase SC sustainability.

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