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Evaluation of green supply chain of small and medium manufacturing companies based on green productivity indicators using fuzzy inference system

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Abstract

Environmental pollution has become a green motivation to control the pollution increase in countries which its purpose is to reduce the negative effects of environmental pollution; hence, green chain supply management has an important role in the environmental impact of organizations. Therefore, the purpose of this study is to evaluate the green supply chain of small and medium manufacturing companies based on green productivity indicators. This research is based on practical purposes and quantitative research approaches. The statistical sample was designated by 297 small and medium manufacturing companies in East Azerbaijan province. In order to data collection, a researcher-made questionnaire based on the research literature has been used. The validity of the questionnaire was determined based on the validity of the structure and its reliability using Cronbach's alpha coefficient. To evaluate the green supply chain through green productivity indicators, a fuzzy inference system based on triangular membership functions, Mamdani inference and dependency rules has been used. The results show that the designed inference system based on green productivity indicators to evaluate the green supply chain with 43 dependency rules is able to evaluate the greenness measure of the supply chain of companies based on numerical values and linguistic words.

Keywords: Supply Chain Evaluation, Green Productivity, Fuzzy Inference System

1. Introduction

Due to increasing environmental pressures and interest in economic comfort, green supply chain management has appeared as an important strategy that can contribute to the stable upgrade of

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performance [1, 2, 3]. In fact, the concept of green supply chain management is the integration of environmental thought with supply chain management, [3, 4, 5, 6, 7]. As environmental restrictions increase, companies need to effectively implement green supply chain management activities and improve their environmental image [8, 9, 10, 11].

According to [12], the implementation of green supply chain activities has many problems. It can effectively check related activities that assess the environmental performance of suppliers according to the needs of each country and region. Supply chain management is considered as an important concept in management strategies [13, 14, 15]. They define supply chain management as the integration of internal organizational decisions with external factors. According to Gilbert study [16], green supply chain management considers all supply chain activities in terms of their impact on the environment.[17] show that acceptance of green supply chain activities helps organizations to reduce environmental risks and improve material and energy consumption [18, 19].

Lamming and Hampson [20] analyzed the use of some beneficial activities such as wastage management and product monitoring. They linked the use of these tools to supply chain activities to make a friendly policy of environment with suppliers and help improve it. Unlike Lamming and Hampson study (1996), Lippmann [21] suggests various activities and steps that an organization can accept to improve its environmental performance (such as green supply chain policies, suppliers selection, senior management, reciprocal participation, suppliers evaluation and having supportive relationships with customers and suppliers). [22] identifies three groups of good activities: policy, product / process, and performance evaluation. His results show that senior management support is the most important contributing factor in achieving environmental measures. At the same time, Bowe et al. [23] have identified three types of supply chains: 1) the process of greening that considers suppliers relationships and recycling; 2) product-based green supply that involves dealing with waste products and 3) advanced green supply which includes activities such as consumer performance evaluation, participation programs of clean technologies with suppliers, and risk sharing in environmental standards.

In 2006, [24]t identified four critical aspects of Taiwan's electronics industry using the hierarchical method of fuzzy analysis which include supplier management, product recycling, organizational involvement and lifestyle management. Another interesting study was suggested by [25]. Their results suggest that organizations should share sustainability-related information such as customer / supplier purchasing policies, goals and prospects. In addition, environmental standards such as ISO 14001 or EMAS must be identified. They also suggested that suppliers' performance could be improved by periodic inspections and through participation with suppliers. In [26] evaluated and defined the triggers and activities of green supply chain among several manufacturing organizations in China. The obtained result highlights the importance of international standards such as ISO 14001. In addition, they concluded that environmental awareness has improved as a competitive marketing environment due to external pressures. They also believe that top and middle class managers' support is considered as an important factor in the effective implementation of green supply chain activities. In [27] conducted a study considering small and medium organizations and comparing the effect of buyer behavior on suppliers' environmental competencies. They concluded that factors such as "environmental protection", "external tools", "green supply chain" and "development of internal capabilities of environmental management" contribute to the development of the environment. Recently, [28] conducted a study on identifying critical factors of green supply chain activities in the Indian automotive industry. They divided green supply chain activities into 15 main factors and then 113 sub-factors. The aim of their study was to rank the critical factors of green supply chain .Their results suggest that top management support is the most important factor in the success of the green supply chain. In [29] suggested using structural-interpretive modeling in the study of various

factors affecting the green supply chain in the Indian mining industry. The results of their research support the result proposed by Toke et al. Their results also prove that top management support is the most important trigger in green supply chain success. The results of [30] study are different from the studies of [31, 32**?**] and Luthra et al. because they developed a set of factors called "critical success factors (CSF)" in the successful implementation of the green supply chain.
In research, various tools have been mentioned to evaluate the green supply chain [33, 35]). According to the studies and the definition of supply chain, which includes all activities that are performed in the field of purchasing, preparation, change and conversion, and logistics in general [36, 37, 38], green supply chain evaluation indicators can be classified into four main groups. These activities relate to (1) inbound operations, (2) production operations, (3) outbound operations, and (4) reverse logistics. Table (2) shows the supply chain evaluation indicators in these four areas.

Table 1: Green supply chain evaluation indicators based on green productivity

Indication	Structure
Selection of suppliers based on environmental indicators(A11)	Inbound operations
Supporting suppliers to develop environmental programs (A12)	
Encourage suppliers to take environmental actions (A13)	
Purchasing Environment friendly materials and products (A14)	
Monitoring and auditing environmental conformity (A15)	
Pollution prevention programs (A16)	
Environmental Managers and Employee Training (A17)	
Design of products for recycling (A21)	Production operations
Use of Clean Technology (A22)	
Improving the use of capacity (A23)	
Promotion of reproduction (A24)	
Integration of internal process and production automation (A25)	
Using hardware and energy efficient centers (A26)	
Increasing the operational efficiency of vehicles (A31)	Outbound operations
Reduction of wastage related to obsolete equipment (A32)	
Use of environmental friendly packaging (A33)	
Reduction of unused capacity in various elements of production and transmission (A34)	
Improvement of vehicle routing using GPS (Global Positioning System) and other systems (A35)	
Reduction of accidents or environmental fines (A36)	
Reduction of energy consumption (water, electricity, fuel, etc.) (A37)	
Reuse of products and components (A41)	Reverse logistics
Reverse logistics	
Resale of used components (A42)	
Material recycling (A43)	
Waste management (A44)	
Taking back product packaging such as pallets, boxes, etc. (reuse product packaging) (A45)	
Collection of final products (out of specification, malfunctions, damaged in shipping, etc. products) (A46)	

[39, 40] Inbound operations include purchasing and regulating the inbound movement of raw materials, components and elements to a manufacturing company. Production operations include a set of methods for environmental friendly production and design throughout the supply chain. The outbound operation consists of a set of methods that determine the result of the previous step. Finally, there is reverse logistics, which is related to the circulation of products and materials in the opposite direction of the flow in forward logistics [41]. One of the appropriate frameworks for evaluating the green supply chain of companies is the fuzzy inference system on the basis of green productivity indicators. Fuzzy inference system can work as a decision support system and managers of organizations can check the compatibility and adaptation of their supply chain with environmental issues at any time and place, and make appropriate decisions to improve the green supply chain. However, rules creation in the fuzzy inference system relies on personal judgments of individuals, which can make the inference rules and thus the outbound of the system to rely on the individuals opinions. While the extraction of dependency rules includes a category of data mining problems in which we seek to extract and define the rules and patterns that provide more accurate description of the data governing space and are avoided relying only on judgment. Therefore, the purpose of this paper is to evaluate the green supply chain of small and medium manufacturing companies based on green productivity indicators using a combination of dependency rules and fuzzy inference system.

2. Tools and methods

This research is based on practical purpose and is based on quantitative research approach. In this research, a fuzzy inference system has been designed to evaluate the green supply chain of small and medium manufacturing companies. To this end, confirmatory factor analysis has been used to identify inbound variables and validate the research literature extracted structures (Table (1)) and ensure that these structures in the statistical population of small and medium manufacturing companies are also approved as green supply chain tools. For this purpose, a questionnaire based on the references in Table (1) was designed. The statistical population in this section was all active small and medium companies in East Azerbaijan province. The statistical sample was randomly selected. Due to the existence of 1300 active small and medium companies operating in East Azerbaijan province, the statistical sample based on Krejcie and Morgan table, 297 companies have been determined which research questionnaires have been provided to the managers of these companies. The validity of the questionnaire was evaluated based on the validity of the structure using confirmatory factor analysis, the results of which are presented in Table (3). The reliability of the questionnaire was calculated based on Cronbach's alpha coefficient and also separately for each structure. Cronbach's alpha formula is located at the bottom of Formula (2.1). The results are shown in Table (2), where k is the number of items, S^2 is the variance of the total scores of each respondent, and Si2 is the variance of the scores for item i. (Formula (2.1) Cronbach's alpha)

$$\alpha = (\frac{k}{k-1})(1 - \frac{\sum_{i=1}^{k} S_i^2}{S^2}) \tag{2.1}$$

Table 2: Cronbach's alpha coefficient value according to the structures

Cronbach's alpha coefficient value	Structure
%902	Inbound Operation
%870	Production Operation
%895	Outbound Operation
%879	Reverse logistics

Given that the results of Table (2) show that the Cronbach's alpha value for all research structures is calculated to be greater than 0.7, accordingly the reliability of the questionnaire can be confirmed. In the next step, after identifying and confirming the research structures (inbound variables), a fuzzy inference system is developed. Triangular numbers (Formula 2.2), Mamdani inference (Formula 2.3) were used to formulate the fuzzy inference system, and the GRI method, which is one of the methods for formulating dependency rules, was used to formulate the rules. The GRI algorithm discovers the communication rules in data. Rules inference is a method of generating a set of rules that categorize cases. Although decision trees can create a set of rules, rules inference methods create a set of independent rules that do not necessarily create a tree.
Because rules inferentialist does not have to divide at any level, and can look to the future, it is able to find different and sometimes better patterns for classification. Unlike trees, the created rules may not cover all possible cases. Also, unlike trees, the rules may be in conflicting predictions that in each case a rule must be chosen to follow. One way to resolve these conflicts is to assign a degree of confidence to each rule, and use a rule that has a higher degree of confidence. The algorithm is constantly growing in a loop, making rules and pruning until all data is finished or the error is more than 50%. In the iteration phase of this algorithm, the accuracy of the results can be adjusted from zero to 100%. Finally, the evaluation of the green supply chain, using the designed system was firstly performed for all small and medium manufacturing companies, and then, for example, for three companies.
Formula (2.2): The membership function of triangular numbers fuzzy systems (mathematical form of the membership function of a triangular fuzzy number)

$$\mu_M(X) = \begin{cases} 1-\frac{m-x}{\alpha} & m-\alpha \le x \le m, \\ 1-\frac{x-m}{\beta} & m \le x \le m+\beta, \\ 0 & otherwise \end{cases} \tag{2.2}$$

(Formula (2.3): Mamdani inference)

$$output = \frac{\int x, \mu(x)dx}{\mu(x)dx} \tag{2.3}$$

3. Finding

3.1. Confirmatory factor analysis

In order to confirm the inbound variables in the statistical population, confirmatory factor analysis has been used. In performing confirmatory factor analysis, various indicators are used to evaluate the appropriacy of the confirmatory model. The main indicators used in various researches are Goodness of Fit Index (GFI) Formula (3.1), Adjusted Goodness of Fit Index (AGFI) Formula (3.2), Comparative Fit Index (CFI) Formula (3.3), Normalized Chi-square Index (CMIN) Formula (3.4), the Root Mean Squared Error Approximation (RMSEA) Formula (3.5) and the Root Mean Residual (RMR), which were also used in this study to evaluate the quality of confirmatory models. The results of confirmatory factor analysis are shown in Table (3). Formula (3.1); Goodness of Fit Index (GFI)

$$GFI = \frac{F_M}{F_{IND}} \tag{3.1}$$

Formula (3.2); Adjusted Goodness of Fit Index (AGFI)

$$AGFI = 1-(1-GFI)\frac{dl_{IND}}{dl_M} \tag{3.2}$$

Formula (3.3); Comparative Fit Index (CFI)

$$GFI = 1 - \frac{F(S, \sum \theta)}{F(S, \sum \dot{()})} \tag{3.3}$$

Formula (3.4); Normalized Chi-square Index (CMIN)

$$X^2 = \sum \frac{(F_0 - F_e)2}{F_e} \tag{3.4}$$

Formula (3.5); the Root Mean Squared Error Approximation (RMSEA)

$$RMSEA = \sqrt{\frac{X^2 - df_{model}}{(N-1) * df_{model}}} \tag{3.5}$$

Table 3: Green supply chain evaluation indicators

RMR	RMSEA	CFI	GFI	CMIN	Factor weight	Refrence	Structure	
0/041	0/046	0/94	0/91	0/96	1/641	0/89	A11	Inbound Operation
						0/72	A12	
						0/69	A13	
						0/70	A14	
						0/76	A15	
						0/77	A16	
						0/72	A17	
0/050	0/065	0/90	0/90	0/93	2/242	0/89	A21	Production Operation
						0/88	A22	
						0/81	A23	
						0/72	A24	
						0/78	A25	
						0/92	A26	
0/046	0/050	0/94	0/92	0/95	1/753	0/71	A31	Production Operation
						0/74	A32	
						0/69	A33	
						0/72	A34	
						0/84	A35	
						0/60	A36	
						0/74	A37	
0/049	0/062	0/91	0/91	0/93	2/138	0/93	A41	Reverse logistics
						0/89	A42	
						0/91	A43	
						0/86	A44	
						0/89	A45	
						0/81	A46	

The results of confirmatory factor analysis for each of the research structures in Table (3) show that the value of the normalized chi-square index (CMIN) for all structures is less than 2, which

indicates the appropriacy of confirmatory models based on this index. The value of Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI) and Comparative Fit Index (CFI) is greater than 0.9 for all structures, which indicates the appropriateness of confirmation models based on these indicators. The value of the Root Mean Squared Error Approximation (RMSEA) is less than 0.09 for all structures, which indicates the appropriateness of confirmation models based on this index. Finally, the Root Mean Residual (RMR) is less than 0.05 for all structures, which indicates that based on this index, all confirmation models have been appropriately validated in the statistical population. Also, the amount of factor weight, which indicates the relationship between the structure and each of the references, is calculated to be greater than 0.5. This value indicates the appropriate relationship between the structure and its associated references.
Based on the results obtained for confirmatory factor analysis, it can be stated that all confirmation models in the statistical population, which have been examined, have been approved. Structures derived from the research literature can also be considered as inbound variables in the study population to design a fuzzy inference system.

4. Fuzzy inference system design

After confirming the components of green supply chain tools of small and medium manufacturing companies, a fuzzy inference system has been designed to evaluate. In designing a fuzzy inference system, the first step is to determine the inbound and outbound variables related to the problem. In this study, the inbounds of the fuzzy inference system for the green supply chain of small and medium manufacturing companies, verified tools through confirmatory factor analysis, including inbound operations, production operations, outbound operations and reverse logistics. The outbound of the system also indicates the greenness of the supply chain. Accordingly, the fuzzy inference system with four inbound variables and one outbound variable is designed as Figure (1).

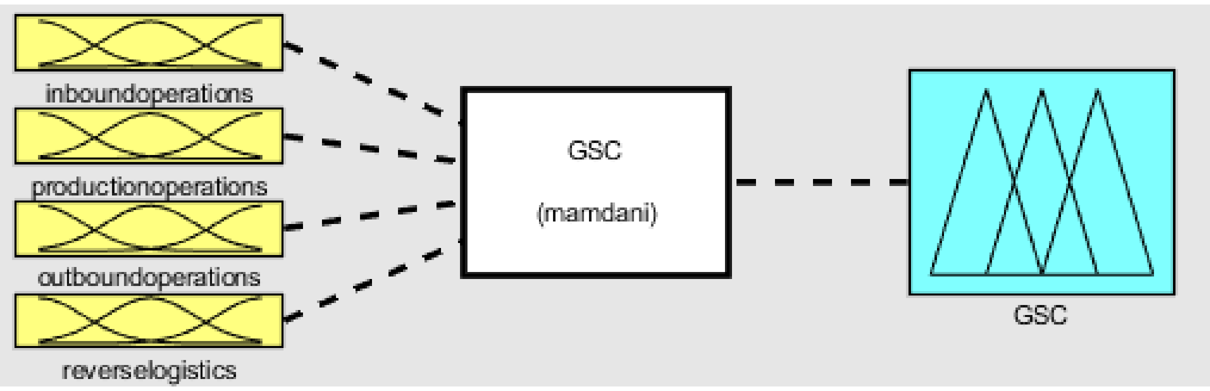

Figure 1: Fuzzy inference system designed in this research

In the following of the fuzzy process, the inbound and outbound variables are based on linguistic words and triangular fuzzy numbers. Table (4) shows the linguistic words and equivalent fuzzy numbers for the inbound variables.

Table 4: Linguistic words and equivalent fuzzy numbers for system inbounds

Equivalent fuzzy number	Reverse logistics	Outbound operations	Production operations	Inbound operations	Inbound
(3, 1, 1)	Inappropriate	Inappropriate	Inappropriate	Inappropriate	
(3, 5, 1)	Somewhat appropriate	Somewhat appropriate	Somewhat appropriate	Somewhat appropriate	
(5, 5, 3)	Appropriate	Appropriate	Appropriate	Appropriate	

Table (5) shows the linguistic words and equivalent fuzzy numbers for the outbound variable.

Table 5: Linguistic words and equivalent fuzzy numbers for system inbounds

Symbol	Equivalent fuzzy number	The greenness of the supply chain	Outbound
mf1	(2, 1, 1)	Very Low	
mf2	(3, 2, 1)	Low	
mf3	(2, 3, 4)	Moderate	
mf4	(3, 4, 5)	A Lot	
mf5	(4, 5, 5)	Too Much	

Given that each of the linguistic words is represented by triangular fuzzy numbers, so the fuzzy numbers related to the outbound variable can be shown for example in Figure (2) in MATLAB software.

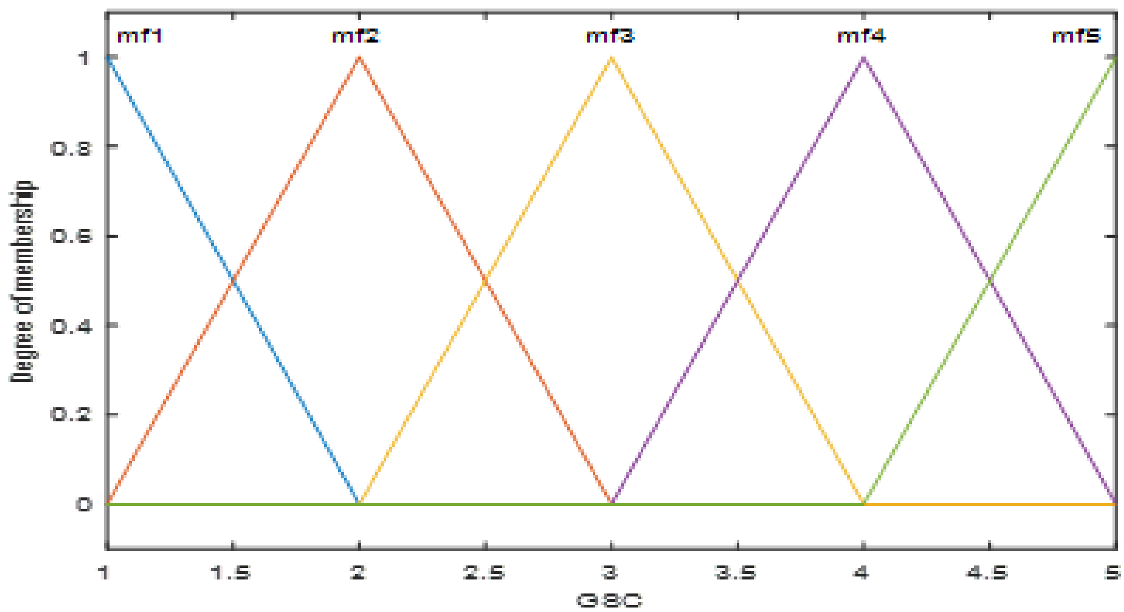

Figure 2: Fuzzy numbers of outbound variables

Fuzzy rules are performed after the fuzzy process of inbound and outbound variables. For this reason, as mentioned, the GRI method is used. In this method, the confidence level of each rule is at least 50%. In other words, a rule would be acceptable which the minimum confidence level is 50%. The results are summarized in Table (6).

Table 6: Part of the dependence rules absorbed by the GRI method

Result	Introduction	Confidence Percentage	Rule Number
Then the greenness of the supply chain will be a lot	If the inbound operations is appropriate	11/74 1	
Then the greenness of the supply chain will be moderate	If the inbound operations is appropriate and the outbound operations is inappropriate	78/77	2
Then the greenness of the supply chain will be a lot	If the inbound operations is appropriate and the outbound operations is appropriate	67/91	3
Then the greenness of the supply chain will be moderate	If inbound operations is appropriate, production operations is somewhat appropriate and outbound operations is inappropriate	00/80	4
Then the greenness of the supply chain will be a lot	If production operations is appropriate and reverse logistics are appropriate	59/70	5
Then the greenness of the supply chain will be too much	If inbound operations, production operations, and reverse logistics are appropriate	100/0	6
Then the greenness of the supply chain will be very low	If production operations and reverse logistics are inappropriate	100/00	7
be very low			
⋮	⋮	⋮	⋮
Then the greenness of the supply chain will be too much	If inbound operation, production operation and outbound operation are appropriate	100/00	44
Then the greenness of the supply chain will be moderate	If outbound operations is appropriate and reverse logistics are somewhat appropriate	100/00	45
Then the greenness of the supply chain will be low	If production operations are somewhat appropriate, outbound operations is appropriate and reverse logistics are inappropriate	100/00	46

The results of Table (6) show that through the use of GRI dependency rules extraction method, 46 rules have been extracted which have entered the rules section of fuzzy inference system. It should be noted that if conventional methods, such as the combination of the introduction part, were to be used, 81 rules would have to be written, given the presence of four linguistic words in each inbound. At this stage, the design of the fuzzy inference system and the formulation of rules are completed. After formulating rules to examine the outbound behaviors and its compliance with the research literature and experts' expectations, the outbound behaviors are examined in three dimensions. Figure (3) shows the four outbound behaviors in the designed system.

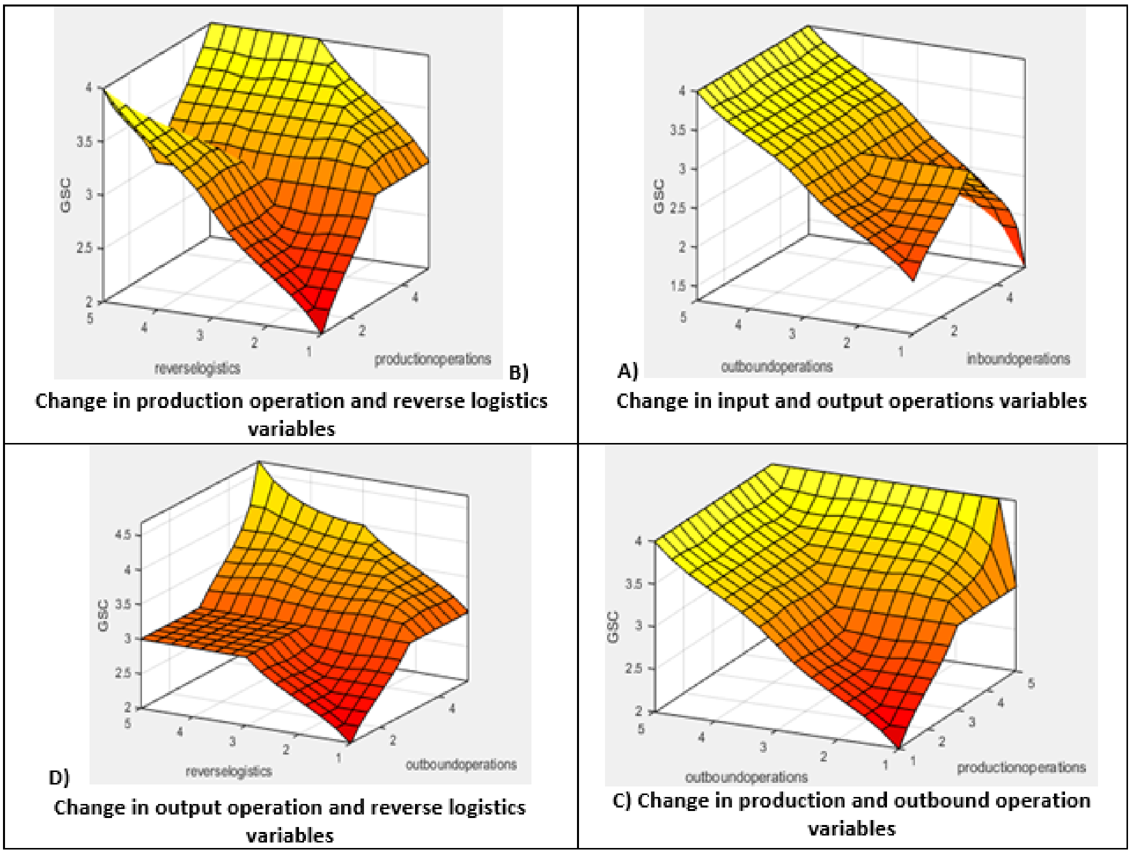

Figure 3: Outbound behaviors in the designed system

The research literature shows that if any company can use supply chain tools properly, the greenness of the supply chain will increase. For example, if the inbound operation is observed in relation to the greenness of the supply chain, it can increase the overall green supply chain. Figure (3) in three dimensions in two parts, shows the behaviors of different inbound variables by keeping constant the other variables. The vertical part of the graphs in Figure (3) is related to the outbound variable. In Figure (3), Section A shows that as the inbound and outbound operations increase, the supply chain becomes greener. Section B shows that as production operations and reverse logistic increase, the supply chain becomes greener. Also, Section C shows that as production and outbound operations increase, the supply chain greenness increases. Sections D (3) shows that as the outbound operations and reverse logistics increase, the greenness of the supply chain increases. The results obtained in this section are in accordance with the research literature and the designed system can be considered suitable for supply chain evaluation. Then, the designed system is used to evaluate the supply chain of small and medium manufacturing companies.

5. Evaluation of green supply chain of small and medium manufacturing companies

The fuzzy inference system takes definite inbounds and fuzzificates them, then converts them to a definite number based on defuzzification. Therefore, in this section, first, the scores average of the questionnaire for each inbound variable is calculated and the scores average is entered into the system. Finally, the outbound of the system indicates the supply chain greenness of companies. To evaluate, first, the greenness of the supply chain of all small and medium manufacturing companies was calculated, and then for three sample companies, this was done based on the scores given. The results of the supply chain greenness assessment are shown in Figure (4) and Table (7) for all small and medium manufacturing companies.

Table 7: The greenness of the supply chain of small and medium manufacturing companies based on the inference system

Outbound value	Outbound	Inbound value	Inbound
3/17	The greenness of the supply chain	3/87	Inbound Operations
		2/56	Production Operations
		3/10	Outbound Operations
		2/12	Reverse logistics

Figure (4) shows the obtained outbound.

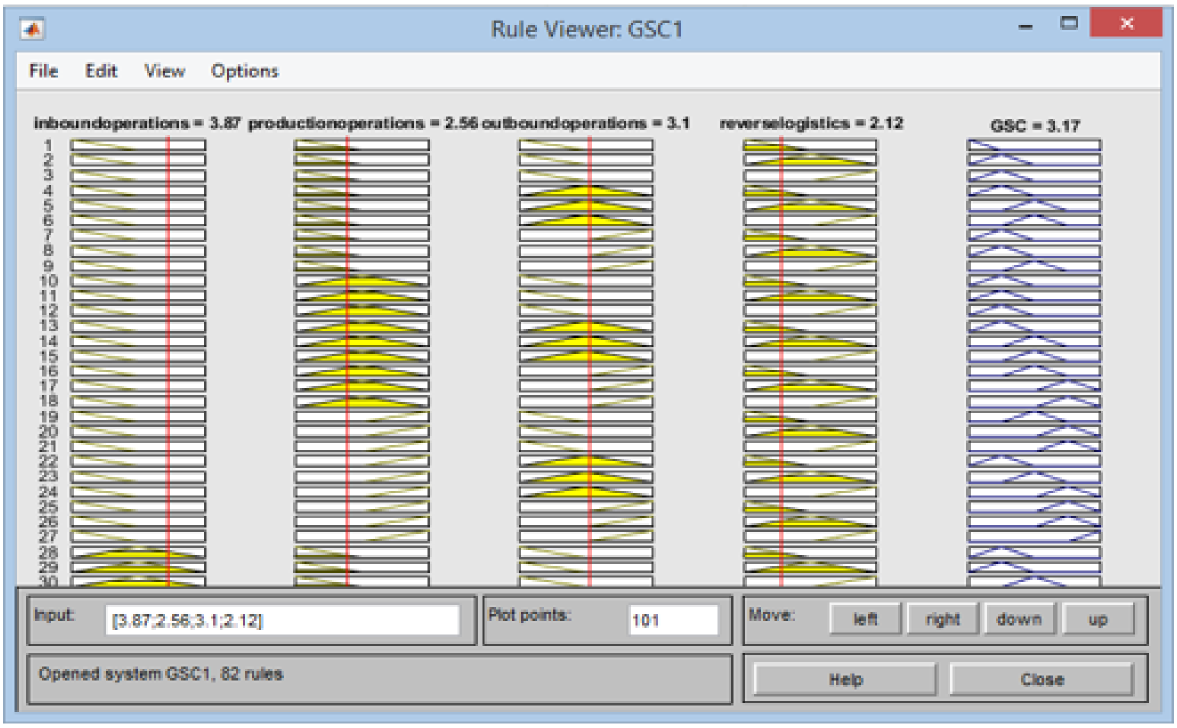

Figure 4: The outbound of Fuzzy inference system in MATLAB software

Converting the obtained value into linguistic words based on triangular membership functions, shows that the greenness of the supply chain of small and medium manufacturing companies with a membership degree of 0.83 is in the average level and with a membership degree of 0.17 is in the high level. In order to show the efficiency of the designed system, this system is used to evaluate the supply chain of three companies as a sample. Table (8) shows the greenness of the supply chain of these three companies.

Table 8: The greenness of the three sample companies based on the designed system

Outbound Value	Inbound Value	Inbound	company
2/90	3/14	Inbound Operations	1
	2/83	Production Operations	
	2/71	outbound operation	
	2/33	Reverse logistics	
3/60	4/16	Inbound Operations	2
	3/67	Production Operations	
	4/00	outbound operation	
	3/86	Reverse logistics	
3/21	3/71	Inbound Operations	3
	1/83	Production Operations	
	4/43	outbound operation	
	2/17	Reverse logistics	

6. Conclusion and discussion

The establishment of green supply chain methods in today's business environment is very widespread among various industries. This popularity requires the development and adoption of appropriate tools to evaluate the performance of green supply chain activities. In this regard, two questions have been highlighted among supply chain researchers. (1)Extraction a list of criteria for evaluating the performance of the green supply chain and (2) developing a decision-making framework that is used for this purpose. For this reason, this research study aims to answer these two questions. To do this, first an extensive review of the literature in line with supply chain management was conducted. Given that one of the most important organizational and inter-organizational divisions is the supply chain of companies, which includes purchasing or preparation, design and distribution activities to customers. The supply chain of companies, especially small and medium companies, is exposed to different customers, suppliers and stakeholders due to the extra-organizational activities of the supply chain. Considering this issue, the first place managers of companies try to bring their activities identical to environmental issues is the supply chain. Although this part is not directly available to the company, companies can try to green the supply chain by adopting various tools and methods. Small and medium companies are more concerned with environmental issues than other companies. These companies are required to have a green and environmental friendly supply chain according to the environmental laws governing on their small and medium destinations. On the other hand, a review of the research literature shows that the first step in greening the supply chain of companies is to be aware of the supply chain situation in relation to green activities. Accordingly, efforts to provide models and methods for evaluating the green supply chain have increased in recent years. The studies of this paper showed that most researchers such as [41, 41, 43, 44] use fuzzy methods due to the ambiguity in the linguistic words to evaluate the greenness of the supply chain of companies

in order to have a correct evaluation of the greenness of supply chain in terms of linguistic words usage.
However, it seems that in all these researches, evaluation requires the existence of similar units so that the evaluator can choose the best green supply chain by comparing these units with each other. While companies need to be able to assess the greenness of their supply chain and plan well to improve performance. In other words, companies should be able to use a method to assess the greenness of their supply chain that this method can help them as a decision support system. In the meantime, one of the appropriate methods for evaluating the green supply chain of companies will be the fuzzy inference system, which can act as a decision support system and companies can at any time and if necessary assess their supply chain compatibility with environmental issues and make appropriate decisions to improve the chain. Accordingly, in this paper, a fuzzy inference system was designed to evaluate the green supply chain of small and medium manufacturing companies. The results showed that the designed system is able to provide an assessment of the greenness of companies at any time and the need for similar units so that managers can be aware of the green status of the supply chain, to eliminate weaknesses and take action to strengthen points.

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