Journal of Applied Research on Industrial Engineering

Vol. 1, No. 2 (2014) 96-111

Journal of

Applied Research on Industrial Engineering

Prioritization of Sustainable Production Indicators Using Fuzzy Inference System

Hadi Shirouyehzad[1] , Sayyed Milad Anvari[2*]

[1]Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran (Hadi.Shirouyehzad@Gmail.com)

[2] Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran (m.anvari@sin.iaun.ac.ir)

ARTICLE INFO

Article history :
Received:
11 June 2014
Received in revised format:
27 July 2014
Accepted:
4 August 2014
Available online:
10 August 2014

Keywords *:*
Sustainability,
Sustainable Production Indicators,
Fuzzy Inference Systems,
Environment,

ABSTRACT

Sustainable production is using non-polluting processes and systems by considering energy conservation and natural resources, which is sustainable in terms of economic, safety and health for employees, society and consumers. In general sustainable production refers to valuable social production for all working people. There are different perspectives on sustainable production indicators. However, some recent researches offered indicators for measuring sustainable production. Increasing the number of indicators causes managers' confusion in using them. This paper offers a fuzzy inference system for indicators ranking in organizations. In this study, general prioritizations regardless of the type of manufacturing industry were considered and effort was focused on showing the relative degree of indicators for managers. So that it offers good understanding about importance of each indicator with regard to others for assessmenting the past, present and future of organizations. The results of the present study shows that beside economy, specialists have great attention on the environmental issues which is important and necessary for manufacturing in protecting natural resources and environments.

1. Introduction

Mutations in the fields of economy, society and technology need constant changes products and related processes. The growing importance of environmental and social aspects has led to the emergence of the concept of life cycle and sustainable production (Boër & Jovane, 1996).

Based on O'Brien (1999) in the "Sustainable production, a new paradigm for the new millennium" article, admits that in the new millennium, manufacturing industries have other

* Corresponding author name: Sayyed Milad Anvari E-mail address: m.anvari@sin.iaun.ac.ir

tasks except producing their wealth, and it is the development of sustainable production systems to minimize environmental impacts. In this context, three questions answered 1) what should manufacturing industry do for sustainable production? 2) Who are the key players? And what should they do to ensure the achievement of sustainable production? 3) How laws and government policies can help to support changing towards sustainable production?

Although Sustainability is still a vague concept, but there is a growing consensus, and it is believed that to move toward sustainable development it is necessary to define indicators for measuring achievements (Tseng et al., 2009). As a result, Companies need to integrate sustainable production indicators with their own resources for ensuring their survival (Tseng et al., 2009). Many organizations have begun to realize the importance of sustainable development, but they are not sure how this concept can be applied in their businesses.

Indicators are suitable scales for measuring and evaluating the current state of the organization and comparing this situation with the past and other organizations. Although common indicators such as levels of energy usage, the amount of water usage, and work-related injuries are used in most organizations, but many differences in production processes caused these views that there is no possibility of providing the same criteria applied to all organizations. However, recent researches provided the frequency indicator for sustainable productions, which are applicable to all manufacturing organizations (Veleva & Ellenbecker, 2001).

Clearly, all organizations which are trying to use indicators of sustainable production, do not have aim for all aspects of the program and sustainable production. It is better for organizations to start working with a number of indicators that are consistent with their goals and after gaining experience gradually began to develop goals and the sustainable production indicators (Veleva & Ellenbecker, 2001). Ranganathan (1998) specifically refers to the fact that without any agreement based on what is measured and how it should be measured, managers will be immersed in a sea of confusing, contradictory, incomplete and incomparable information with others.

The most important weak point observed in previous researches is the failure to prioritize the criteria for organizations. Multiplicity of indicators will cause confusion in the use of indicators for managers. Confusing of managers and organizations will reduce their confusion and reliability of these indicators, although the index may be effective in some organizations, but it does not working in other organizations (Veleva & Ellenbecker, 2001).

In this paper, we discuss the ranking criteria for organizations, and we followed up with surveys of experts and journalists, to introduce indicators, which are important and more common in organizations with the approach of using a fuzzy inference system to administrators in order to achieve sustainable production of an appropriate starting point to move. This study will follow a general approach; it means that, it is not specific to a particular industry and managers in manufacturing and service industries can all benefit from this study. Fuzzy Inference System is a system of fuzzy rule base consists fuzzy rules of If - Then in a fuzzy inference engine (Ferreira & Lapa, 2004). Fuzzy inference system produces fast results in the ranking table by experts' opinion without the need for additional calculations. According to the uncertainty condition, natural language can effectively represent human thought (Zadeh, 1965). In many practical examples, human preference model was in the uncertainty condition and may not be able to allocate the accurate amount of numeric to describe preferable. Because some evaluation criteria are qualitative and describes as verbal expressions, and it is very difficult for a person who decides, to show preferable as the precise numeric values. A very convenient tool for evaluating such criteria is the using of fuzzy sets. Converting Linguistic terms into fuzzy numbers would be very (Tseng et al., 2009). In previous studies held by Veleva & Ellenbecker (2001), the evaluation index of sustainable production due to rapid changing in environment was always in terms of uncertainty condition, and these aspects are measured in terms of language.

In the rest of the article, the second part contains an overview of the research. In the third and fourth sections, we describe the detailed indicators of sustainable production process and fuzzy inference system. Their methodology is described in detail in section V. In section VI We present the findings of this article and in the last section, we will interpret the findings.

2. Literature review

In reviewing the literature, we find that researchers in several papers are attempting to prioritize and evaluate indicators measured in various areas.

Based on the results of an investigation conducted by Han and Han (2004), Intellectual capital is considered as a benchmark for competitive advantages. In this regard, they prioritize and select intellectual capital measurement indicators using an analytic hierarchy process for the mobile telecommunications industry by proposing a decision model based on the analysis of the conceptual framework of the qualitative characteristics of financial information and an examination of information quality of the information system. The application of the analytic hierarchy process makes it possible to extract weights for setting the priority among criteria in the mobile telecommunications industry. Measures examined in this study to prioritize indicators are including, reliability, comparability, connectivity, risk and quality of representation. Based on this research, the connectivity is in the first rank and follows by reliability, comparability, quality representation and risk.

Bozbura and Beskese (2007) investigated improving the quality of prioritization of organizational capital measurement indicators under uncertain conditions. In this regard, a methodology based on the extent the fuzzy analytic hierarchy process (AHP) was applied. Within the model, three main attributes, including deployment of the strategic values, investment to the technology and flexibility of the structure; their sub-attributes and 10 indicators were defined. Researchers in this study determined the priority of each of these indicators, via the experts' preferred gathered questionnaire. The results of the study showed that deployment of the strategic values is the most important attribute of the organizational capital.

According to Bozbura & et al. (2007) people in an organization constitute an important and essential asset which tremendously contributes to development and growth of that company. So they defined a methodology to improve the quality of prioritization of human capital measurement indicators under uncertainty conditions. In this regard, they proposed a methodology based on the extent the fuzzy analytic hierarchy process (AHP). Within the proposed model, five main attributes, including talent, strategical integration, cultural relevance, knowledge management, and leadership; their sub-attributes, and 20 indicators were introduced. The results of the study indicated that creating results by using knowledge, employees' skills index, sharing and reporting knowledge, and succession rates of training programs are the four most important measurement indicators in human capital.

T-Sang et al. (2009) investigated the sustainable production indicators in uncertainty conditions. In this regard for evaluating indicators and considering their interdependence and uncertainty conditions, the fuzzy analytic network processes (ANP) were used. The result of this study is an effective model for assessing indicators of sustainable production and obtaining useful information regarding the hierarchical framework.

Mehralian et al. (2013) in a study, investigated the prioritization of intellectual capital indicators in knowledge-based pharmaceutical industry. In their attempt based on an extensive literature review, a valid and reliable questionnaire was designed. In order to exact prioritization of indicators, fuzzy TOPSIS technique as a MADM model was used. The fuzzy TOPSIS results revealed participants remarked high concerns, especially about knowledge and skills of managers and employees regarding to human capital, high concerns, particularly about positive climate, the ratio of investment in R&D and numbers of R&D projects according to structural capital, while considering the relational capital, more attention was paid to customers and strategic cooperation.

In other studies, researchers are also using fuzzy inference system models for prioritization. In an article, Guimaraes and Lapa (2004) used Fuzzy Inference System, for ranking nuclear transient phase. The authors aim to maximize the use of professionals, and the method presented in the study of Guimaraes and Lapa (2004) was considered as an alternative method for effective ranking that can be used in nuclear power plants.

Amindoust et al. (2012) also use a fuzzy inference system model for ranking sustainable suppliers. In this study, the authors received the expert opinions using verbal variables, then, by applying fuzzy logic and fuzzy inference system, evaluated options and parameters in a case study. The presented model is applicable to all organizations.

3. Indicators of sustainable production process

In this section we defined in detail, the concepts of index, sustainability, sustainable production and sustainable production indicators.

3.1. Concept of index

Veleva & Ellenbecker (2001) has been made a comprehensive analysis on the different definitions of the indicators expressed by "variable," "scale," " statistical scale," "a representative for the scale" and "sub-scale". Finally he concluded that the indicators are variable, the variable can take different values according to the specific type of measurement or observation, so the data are real indicators of measurement or observation. Indicators typically provide key information about the physical, social, and economic system. The indicators help in reviewing causal relationships and analysis of changes, so the indicators are one step after data collection. What data is collected and how that data is used, guide us in the selection of appropriate indicators (Farrell & Hart, 1998). On business performance, managers are very interested in knowing whether their organization has achieved the objectives set or not? And / or what is their place with respect to others? (Veleva & Ellenbecker, 2001)

Each indicator has its own dimensions, which helps us to distinguish indicators from the goals of preliminary data. Lowell (1998) has identified four key aspects of each index to promote a better indicator:

1. Unit of measurement (kilograms, tones, numbers, dollars, percentage, time, etc.)
2. Absolute or modified measurements (e. g, to utter all the energy used in a year) or modified (energy used per unit of product each year.)
3. Measurement period (annual, monthly, 6 months, etc.)

4. Boundaries (be specific about the measurements for organizations such as the production line suppliers, distributors, whole life cycle of a product or material).

3.2. Sustainable production

Lowell Institute is defined sustainable manufacturing as follows:

Production and offering services using processes and non-polluting systems, conserve energy and natural resources, economically sustainable, safe and healthy for employees, communities and consumers, and it should be socially valuable for all working people. (Lowell, 1998).

According to Veleva & Ellenbecker (2001) Sustainable production has six main aspects:

- Using energy and material resources
- Natural environment
- Partnership development and social justice
- Economic Performance
- Workers
- Products

Organizations that want to be sustainable in their daily functioning should monitor these six aspects (Veleva & Ellenbecker, 2001). LCSP* introduced nine guiding principle those are the current indicators, to further promote the concept of sustainable manufacturing into organizations. These principles include: designing and product packaging, preventing waste and nonconforming products, reducing the harms associated with sustained in labor and increasing welfare workers (Quinn et al., 1998). Organizations that intend to remain stable in their daily operations must be thought about the purposes and principles of the LCSP in order to compare sustainable production indicators with their problems (Veleva & Ellenbecker, 2001).

3.3. Indicators of sustainable production

Despite different views on sustainable production indicators, some recent researches offered indicators to measure sustainable production. The indicators related to sustainable business, focused on environmental aspects of production (Tseng, 2013). However, Veleva & Ellenbecker (2001) suggest that indicators should include measures of economic and social sustainable production as well. Indicators of sustainable production and sustainable development indicators are similar because they emphasized in all dimensions of sustainable development, the environment, society and economics. The difference is that the index of sustainable production has been developed primarily for production equipment, and their aim is to address key aspects of the production, use of energy materials, environment, development participation and social justice, economic performance, labors and the products (Veleva & Ellenbecker, 2001). The use of such indicators creates a continuous evolutionary process of business transformation through raising awareness and improving dialogue with stakeholders (Veleva & Ellenbecker, 2001). Twenty two sustainable production indicators presented in the research of Veleva & Ellenbecker (2001) are listed in appendix (Table 4) besides objective and measurable criteria for each indicator are provided.

Indicators of sustainable production also play an important role in promoting organizational learning. As a part of the feedback system, measurements help managers that are moving in the right direction or need to be improved. Therefore, measurements are part of any adaptive

* Lowell Center for Sustainable Production

learning system (DiBella & Nevis, 1998). Organizational learning is essential for the organization to survive, especially in today's global economy. Commerce businesses need to look carefully at their practices and customer requirements to react fast in necessary situation (Veleva & Ellenbecker, 2001).Vollmann (1996) argues that in many cases, the path is more important than the destination. Measurement process, involving all staff, helps raise awareness and skills and ultimately build intellectual capital of the organization.

In summary, the following are the objectives of sustainable indicators (Veleva & Ellenbecker, 2001):

- Training of organization on sustainable production
- Informing decision makers by providing concise information about the current status and trends in organizational performance
- Promoting organizational learning
- Providing organizations with the tools of measurement to reach sustainable production goals (internal benchmarking)
- Comparing the organization's performance in aspects of production environment, social, professional and economic (external benchmarking)
- Providing a means for mutual assessment mission and report the results to stakeholders
- Providing a tool to encourage shareholders to participate in the decision making processes

4. Fuzzy Inference

4.1. Linguistic variable and fuzzy theory

According to the uncertainty condition, natural language can effectively represent human thought (Zadeh, 1965). The theory of fuzzy sets uses linguistic variables rather than the natural language. Because in many evaluations, there is not any possible assigning for numerical values (Tseng et al., 2009). Many studies due to the uncertainty condition applied fuzzy set theory to solve the fuzzy problem.

Linguistic information is a variant in which the value of a variable is expressed (i.e the value of language) for phrases or sentences in a natural language (Von Altrock, 1966). Linguistic variable is a useful method for when the situation is described as qualitative terms. (Asan et al., 2004).

4.2. Fuzzy inference

Fuzzy inference system is a system containing a set of fuzzy rules including the fuzzy IF-THEN rules and uses a fuzzy inference engine. IF-THEN rules is for determining a mapping from fuzzy sets in the input universe of discourse universe of discourse based on the principles of fuzzy logic and fuzzy output. IF-THEN rules are as follow:

$$R^{(l)}: IF\ x_1\ is\ F_1^l\ and\ \dots\ x_n\ is\ F_n^l \quad THEN\ y\ is\ G^l, \tag{1}$$

Where F_1^l and G^l are fuzzy sets $x = (x_1, \dots, x_n)^T \in U\ and\ \ y \in V$ are the input and output variables of language, and $l = 1,2, \dots, M$. It is shown that these IF-THEN rules, provides an appropriate framework for combining expert knowledge. IF-THEN rules defines $F_1^l x \dots tx F_n^l \Rightarrow G^l$ in $U \times V$ space.

In order to use a fuzzy inference system in engineering systems, where inputs and outputs are real variables, the most straightforward way is adding a fuzzy system in the input and a finalizer in the output. The inputs fuzzy agent changes crisp points to fuzzy sets and the output fuzzy finalizer results in certain definite points. Fuzzy inference introduced by Mamdani (1974) and was successfully used in various industrial processes (Guimaraes and Lapa, 2004).

Fuzzy inference process has five stages; the input of this process is x and y that are both Crisps. Figure1 shows the fuzzy inference system (Khanlari, 2008):

1. Fuzzification of inputs:
   - Fuzzification of the variables in rule 1 results in: A1 (x), B1 (y)
   - Fuzzification of the variables in rule 2 results in: A2 (x), B2 (y)
   - Fuzzification of the variables in rule 3 results in: A3 (x), B3 (y)
2. Application of fuzzy operation (and = min, or = max):
   - Fuzzy Operations for rule 1: max (A1 (x), B1 (y)
   - Fuzzy Operations for rule 2: min (A2 (x), B2 (y)
   - Fuzzy Operation for rule 3: max (A3 (x), B3 (y)

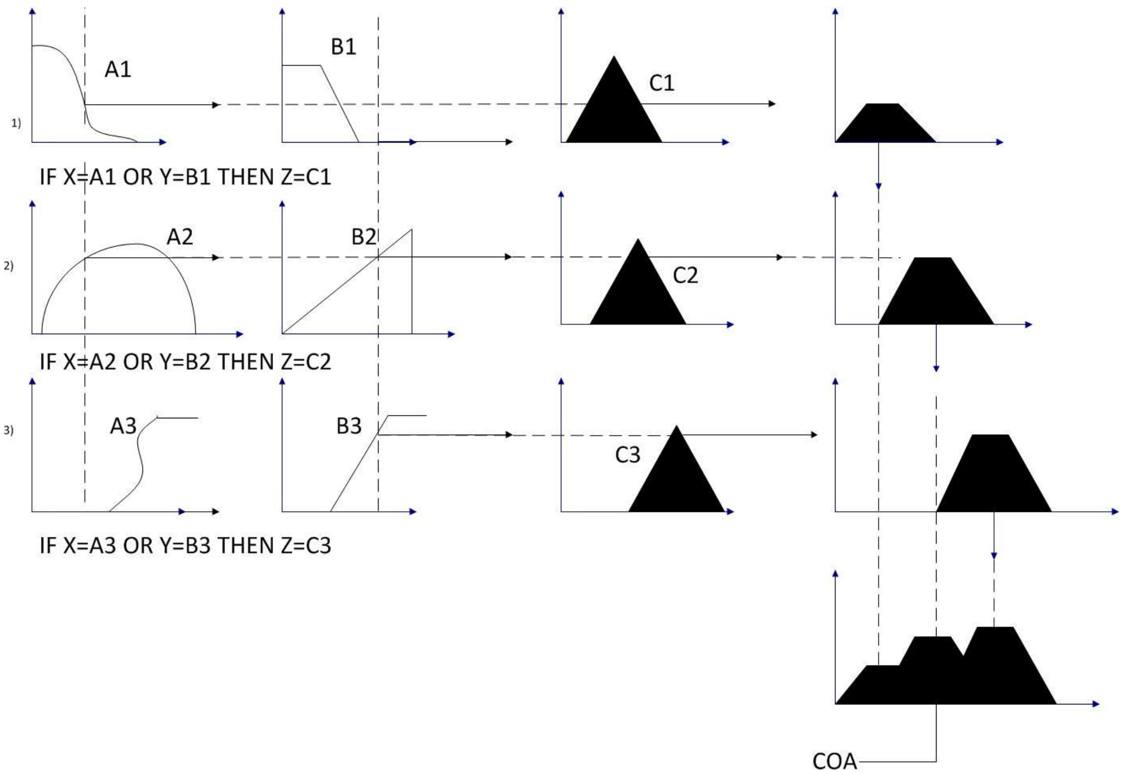

Figure1 A general example of the fuzzy inference system (Zafiropoulos and Dialynas, 2005)

3. Application of implication method (min)
   - Implication for rule 1: C1 = min (C1 (max (A1 (x), B1 (y)
   - Implication for rule 2: C2 = min (C2 (max (A2 (x), B2 (y)
   - Implication for rule 3: C3 = min (C3 (max (A3 (x), B3 (y)
   - Application of aggregation method (max).

The result of equation (2) creates a space. Z_i Represents the weight of each of the rules.

$$E = \max(z_1 \times C_1, z_2 \times C_2, z_3 \times C_3) \quad (2)$$

4. Application of defuzzification (the centre of area COA). Crisp methods used to calculate the output of the center of E, is calculated by means of Equation 3.

$$C = \frac{\int E(x)xdx}{\int E(x)dx} \quad (3)$$

5. Materials and method

In the proposed approach, a fuzzy inference system by collecting opinions of experts for each constituent based on the characteristics and parameters as input data, results in the output data which is in a table ranking (Guimaraes and Lapa, 2004).

In this study, a group of experts consisting three people, rating to the sustainable production based on two criteria: universality and importance. A commonly of an index means its spread among agencies with any kind of productive activity and economic, and the importance of an index means that how much it can help to the indicator to show better current situation in the business and help identifying critical condition. Scores given by experts on criteria of importance and universality is listed in Table1. The data was collected by distributing questionnaires among experts.

Average scores used as input crisp for fuzzy inference systems. For each criterion (importance and Universality), a same membership function was used as Figure 2 and for output variables membership function as shown in Figure 3 was used.

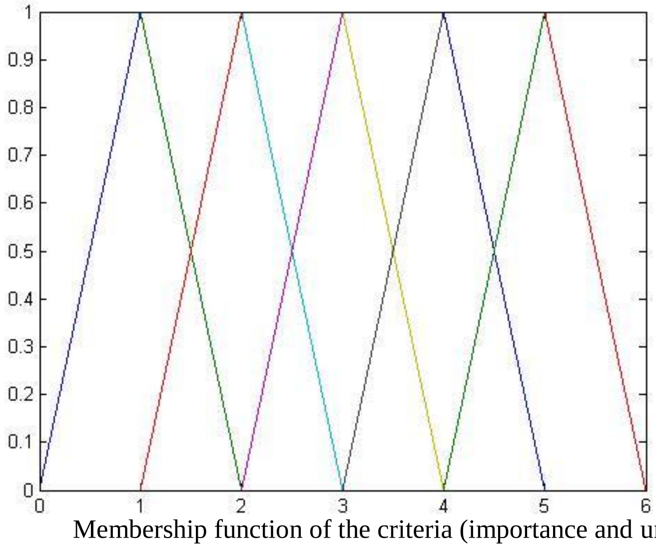

Figure2 Membership function of the criteria (importance and universality)

Table1 Scores given by the experts based on criteria of universality and importance

No	Indicator	Universality	Importance
1	Freshwater consumption	4.33	4
2	Materials used	4.66	4.33
3	Energy use	4.33	4.33
4	Percent energy from renewable sources	3.66	4
5	Kilograms of waste generated before recycling	3.66	4
6	Global Warming Potential	3.33	3.66
7	Acidification potential	3	4.33
8	Kilograms of persistent, bio accumulative and toxic (PBT) chemicals used	4	4.33
9	Costs associated with EHS compliance	3	3.33
10	Rate of customer complaints and/or returns	4	3.66
11	Organization’s openness to stakeholder involvement in decision-making process	3.66	3
12	Community spending and charitable contributions as percent of revenues	2	3
13	Number of employees per unit of product/dollar sale	3	3
14	Number of community company partnerships	2.33	2.66
15	Lost workday injuries and illness case rate (LWDII)	3.33	3.66
16	Rate of employees’ suggested improvements in quality, social and EHS performance	3	4
17	Turnover rate (or average length of service of employees)	3	3
18	Average number of hours of employee training	3.33	3.66
19	Percent of workers who report complete job satisfaction	2	3.66
20	Percent of products designed for disassembly, reuse or recycling	3	4
21	Percent of biodegradable packaging	3.66	3.66
22	Percent of products with take back policies in place	3.66	4

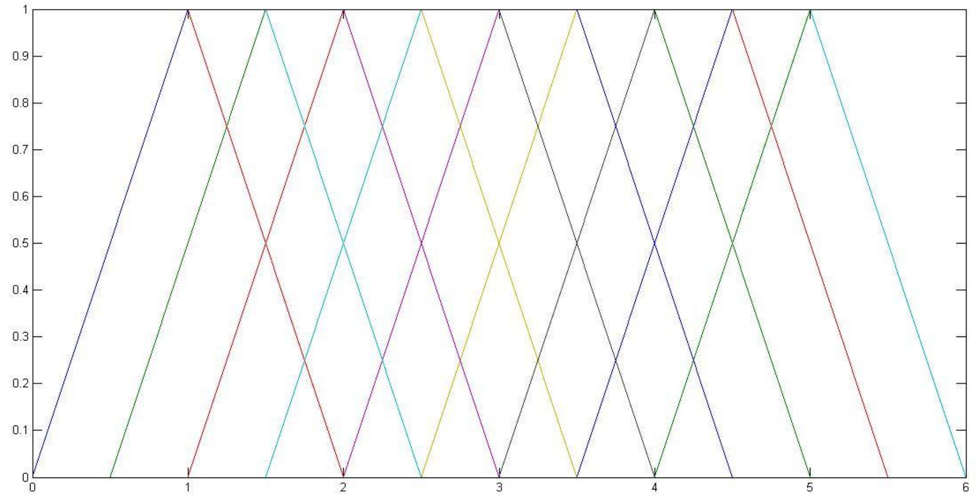

Figure3 Membership function of the output variable

To build the Fuzzy Inference System, Toolbox software MATLAB, V.7.12, (2012) was used. In this paper, a set of 25 rules for fuzzy inference system has been considered and all possible conditions were considered. It should be noted, for example ($\tilde{2}$), is a triangular fuzzy number which is approximately 2 that is illustrated in Figure 4.

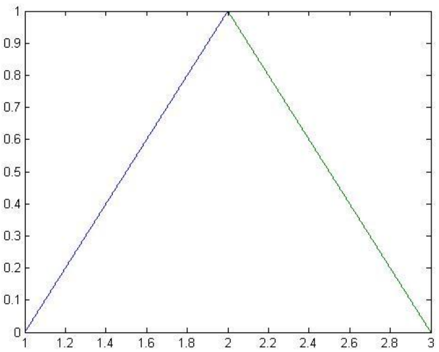

Figure 4

1. If (importance is VL) and (universality is VL) then ($\tilde{1}$)
2. If (importance is VL) and (universality is L) then ($\widetilde{1.5}$)
3. If (importance is VL) and (universality is M) then ($\tilde{2}$)
4. If (importance is VL) and (universality is H) then ($\widetilde{2.5}$)
5. If (importance is VL) and (universality is VH) then ($\tilde{3}$)
6. If (importance is L) and (universality is VL) then ($\widetilde{1.5}$)
7. If (importance is L) and (universality is L) then ($\tilde{2}$)
8. If (importance is L) and (universality is M) then ($\widetilde{2.5}$)
9. If (importance is L) and (universality is H) then ($\tilde{3}$)
10. If (importance is L) and (universality is VH) then ($\widetilde{3.5}$)
11. If (importance is M) and (universality is VL) then ($\tilde{2}$)
12. If (importance is M) and (universality is L) then ($\widetilde{2.5}$)
13. If (importance is M) and (universality is M) then ($\tilde{3}$)
14. If (importance is M) and (universality is H) then ($\widetilde{3.5}$)

15. If (importance is M) and (universality is VH) then ($\tilde{4}$)
16. If (importance is H) and (universality is VL) then ($\widetilde{2.5}$)
17. If (importance is H) and (universality is L) then ($\tilde{3}$)
18. If (importance is H) and (universality is M) then ($\widetilde{3.5}$)
19. If (importance is H) and (universality is H) then ($\tilde{4}$)
20. If (importance is H) and (universality is VH) then ($\widetilde{4.5}$)
21. If (importance is VH) and (universality is VL) then ($\tilde{3}$)
22. If (importance is VH) and (universality is L) then ($\widetilde{3.5}$)
23. If (importance is VH) and (universality is M) then ($\tilde{4}$)
24. If (importance is VH) and (universality is H) then ($\widetilde{4.5}$)
25. If (importance is VH) and (universality is VH) then ($\tilde{5}$)

In Table2 for better illustration of rules, criteria of universality and importance was considered and shown two by two. For example, when the input parameters have average importance and output parameters have low universality, the output results in approximately 2.5. Crisp inputs, which are the result of a poll conducted by experts, was entered to the fuzzy inference system. In this regard in all the rules first, the crisp values entered into the membership function of both criterions (importance and universality). The result is the creation of a number between [0,1] in each of the rules. In the next step, the maximum levels are used to determine the grade awarded to the result. In the third step, the degrees awarded by the rules, will determine the outcome space. In the fourth phase, spaces generated by each law, which are getting together according to their weights. In the fifth stage, the center of this area is calculated by Equation (3) which is the fuzzy inference system output. This rating is the result of expert opinion.

Table2 Rules shown 2 by 2

criteria	**degree**	**universality**				
		Very low	**low**	**Medium**	**high**	**Very high**
importance	Very low	$\tilde{1}$	$\widetilde{1.5}$	$\tilde{2}$	$\widetilde{2.5}$	$\tilde{3}$
	Low	$\widetilde{1.5}$	$\tilde{2}$	$\widetilde{2.5}$	$\tilde{3}$	$\widetilde{3.5}$
	Medium	$\tilde{2}$	$\widetilde{2.5}$	$\tilde{3}$	$\widetilde{3.5}$	$\tilde{4}$
	High	$\widetilde{2.5}$	$\tilde{3}$	$\widetilde{3.5}$	$\tilde{4}$	$\widetilde{4.5}$
	Very high	$\tilde{3}$	$\widetilde{3.5}$	$\tilde{4}$	$\widetilde{4.5}$	$\tilde{5}$

Figure 5 shows the stages of the research. As it is shown in the figure, definition and evaluation of indicators is the first step of the investigation. These indicators are identified based on the comments of experts or through literature. In the next step, index membership function and the FIS rules along with membership function variable output, likewise indicators, can be determined according to the comments of experts or through literature. Then the questionnaire is designed and comments of experts on indicators are categorized. In the next stage, the FIS can be built in Matlab software. Then, the questionnaires data are entered in Matlab software. In the final step, the outputs of Matlab software are analyzed.

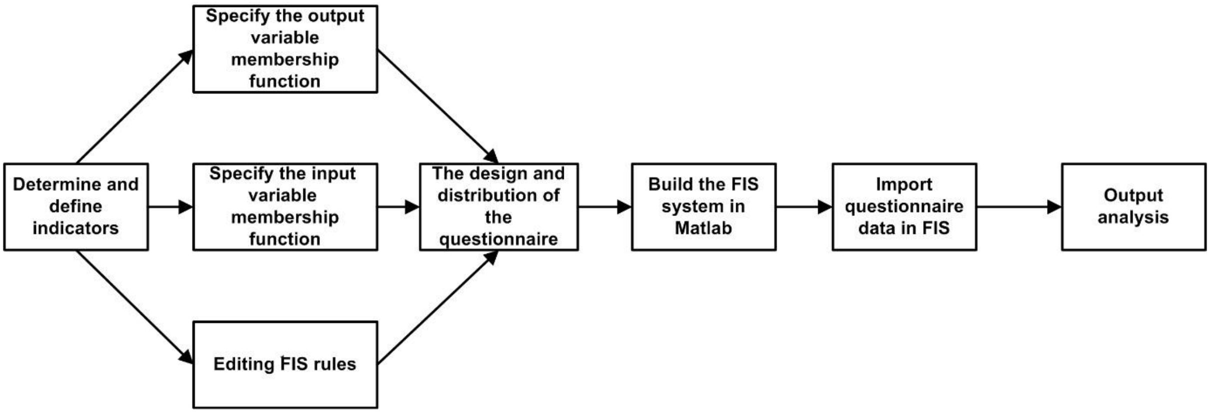

Figure 5

6. Findings

With using Fuzzy Inference System and Toolbox software MATLAB, V7.12, (2012) after entering the data into the software environment, the results obtained from the ranking results in Table 3.

The rank of the indexes in this table derived from the fuzzy inference system which is specified for each indicator. The following parameters in this table are arranged in order from highest to lowest rated.

Table3 Ranking results of indicators

Rank	Indicator	FIS
1	Materials used	4.22
2	Energy use	4.06
3	Freshwater consumption	4.06
4	Kilograms of persistent, bio accumulative and toxic (PBT) chemicals used	4.06
5	Rate of customer complaints and/or returns	3.83
6	Percent energy from renewable sources	3.83
7	Kilograms of waste generated before recycling	3.83
8	Percent of products with take back policies in place	3.83
9	Acidification potential	3.67
10	Percent of biodegradable packaging	3.63
11	Average number of hours of employee training	3.5
12	Global Warming Potential	3.5
13	Lost workday injuries and illness case rate (LWDII)	3.5

Table3 Ranking results of indicators

Rank	Indicator	FIS
14	Percent of products designed for disassembly, reuse or recycling	3.5
15	Rate of employees' suggested improvements in quality, social and EHS performance	3.5
16	Organization's openness to stakeholder involvement in decision-making process	3.33
17	Costs associated with EHS compliance	3.17
18	Turnover rate (or average length of service of employees)	3
19	Number of employees per unit of product/dollar sale	3
20	Percent of workers who report complete job satisfaction	2.83
21	Community spending and charitable contributions as percent of revenues	2.5
22	Number of community company partnerships	2.5

7. Discussion and conclusions

LCSP defines sustainable production as follow: Production and offering services using processes and non-polluting systems, conserve energy and natural resources, economically sustainable, safe and healthy for employees, communities and consumers, and it should be socially valuable for all working people. (Lowell, 1998).

According to Veleva & Ellenbecker (2001) Sustainable production has six main aspects: Using energy and material resources, Natural environment, Partnership development and social justice, Economic Performance, Workers, Products.

In this paper, a fuzzy inference system was used for rating the sustainable production indicators. The fuzzy inference system, is a system that includes a set of fuzzy rules, including IF-THEN rules that uses a fuzzy inference engine (Guimaraes and Lapa, 2004). The fuzzy inference system by the expert panel, without the need for additional calculations produces fast results in the ranking table (Guimaraes and Lapa, 2004). According to the uncertainty condition, natural language can effectively represent human thought (Zadeh, 1965).

Veleva & Ellenbecker (2001) introduced 22 indicators for sustainable production. The use of multiple indicators in the management of indices can be confusing. Confusion managers and organizations reduce their confidence to the indicators. Ranganathan (1998) specifically refers to the fact that no agreement on the basis of what should be measured and how it is measured, the directors will be in a sea of unsettle, contradictory, incomplete, incomparable information. It is clear that all organizations that are going to use this approach, do not have targeted programs to all aspects of sustainable production. It is better for organizations to start with a number of indicators that are consistent with their goals and after gaining experience gradually began to expand the goals of sustainable production (Veleva & Ellenbecker, 2001). This research prioritized basic indicators of economic activity and regardless of the manufacturing industry and organizations, tries to show the relative importance of these indicators until managers with an understanding of each index position relative to other indicators that could assess the current situation and take decisions to improve the current situation. Based on the findings, economic indicators such as the amount of raw materials used in production (per unit) and the amount of using energy (per unit) are at the top and indicators related to the environment, including the use of water consumption (per unit), the use of toxic chemicals and the amount of emissions (global warming potential) is in second place.

The findings indicate that after economy, environmental problems as a significant subject have indicated that it is important for manufacturing industries to maintain natural resource and environment. Due to limited resources and the crucial issue of water, it being a top concern of experts who related to the environment. However, the important issue is that how we can measure the indicators and what is the reaction of companies about it. Maybe it can be the next subject of researchers in the future. Also, fuzzy multi-attribute approaches such as fuzzy TOPSIS and fuzzy outranking methods can be used for the prioritization of Sustainable Production Indicators. The results obtained can be compared with this paper.

8. Acknowledgments

The authors wish to acknowledge Dr. Esmaeilian, Dr. Houmayoni and Mr. Sayyed Mehrdad Anvari for their help in the process of writing this article.

9. References

Amindoust, A., Ahmed, S., Saghafinia, A. and Bahreininejad, A. (2012). “Sustainable supplier selection: A ranking model based on fuzzy inference system”. *Applied Soft Computing*. Vol. 12, No. 6, pp. 1668–1677.

Asan, U., Erhan Bozdag, C., and Polat, S. (2004). “A fuzzy approach to qualitative cross impact analysis”. *Omega – International Journal of Management Science*. Vol. 32, No. 6, pp. 443–458.

Boër, C.R. and Jovane, F. (1996). “Towards a New Model of Sustainable Production: ManuFuturing”. *CIRP Annals - Manufacturing Technology*. Vol. 45, No. 1, pp. 415–420.

Bozbura, F.T. and Beskese, A. (2007). “Prioritization of organizational capital measurement indicators using fuzzy AHP”. *International Journal of Approximate Reasoning*. Vol. 44, No. 2, pp. 124–147.

Bozbura, F.T., Beskese, A. and Kahraman, C. (2007). “Prioritization of human capital measurement indicators using fuzzy AHP”. *Expert Systems with Applications*. Vol. 32, No. 4, pp. 1100–1112.

Dibella, A. and Nevis, E. (1998). How Organizations Learn: An Integrated Strategy for Building Learning Capability. San Francisco: Jossey-Bass Press,

Farrell, A. and Hart, M. (1998). “What does sustainability really mean?”. *Environment*. Vol. 40, No. 9, pp. 5–31.

Guimaraes, F.A.C. and Lapa, C.M.F. (2004). “Nuclear transient phase ranking table using fuzzy inference system”. *Annals of Nuclear Energy*. Vol. 31, No. 15, pp. 1803–1812.

Han, D. and Han, I. (2004). “Prioritization and selection of intellectual capital measurement indicators using analytic hierarchy process for the mobile telecommunications industry”. *Expert Systems with Applications*. Vol. 26, No. 4, pp. 519–527.

Khanlari, A., Mohammadi, K. and Sohrabi, B. (2008). “Prioritizing equipments for preventive maintenance (PM) activities using fuzzy rules”. *Computers & Industrial Engineering*. Vol. 54, No. 2, pp. 169–184.

Lowell Center for Sustainable Production (1998) Sustainable Production: A Working Definition. Informal Meeting of the Committee Members.

Mamdani, E.H., (1974). "Applications of fuzzy algorithms for simple dynamic plant". *Proceedings of the IEEE*. Vol. 121, No. 12, pp. 1585–1588.

Mehralian, G., Rasekh, H.R., Akhavan, P. and Ghatari, A.R. (2013). "Prioritization of intellectual capital indicators in knowledge-based industries: Evidence from pharmaceutical industry". *International Journal of Information Management*. Vol. 33, No. 2, pp. 209–216.

O'Brien, C. (1999). "Sustainable production – a new paradigm for a new millennium". *International Journal Production Economics*. Vol. 60–61, No. 1, pp. 1–7.

Quinn, M., Kriebel. D., Geiser, K. and Moure-Eraso, R. (1998). "Sustainable production: A proposed strategy for the work environment". *American Journal of Industrial Medicine*. Vol. 34, No. 4, pp. 297–394.

Ranganathan, J. (1998). Sustainability Rulers: Measuring Corporate Environmental and Social Performance. Sustainable Enterprise Perspectives. World Resource Institute: Washington, DC, Retrieved from:http://www.wri.org/meb/pdf/janet/pdf

Tseng, M.L. (2013). "Modeling sustainable production indicators with linguistic preferences". *Journal of Cleaner Production*. Vol. 40, No. 1, pp. 46-56.

Tseng, M.L., Divinagracia, L. and Divinagracia, R., (2009). "Evaluating firm's sustainable production indicators in uncertainty". *Comput. Ind. Eng*. Vol. 57, No. 4, pp. 1393–1403.

Veleva, V. and Ellenbecker, M. (2001). "Indicators of sustainable production: framework and methodology". *Journal of Cleaner Production*. Vol. 9, No. 6, pp. 519–549.

Vollmann, T. (1996). The transformation imperative: achieving market dominance through radical change. Boston, MA: Harvard Business School Press,

Von Altrock, C. (1996). Fuzzy logic and neurofuzzy applications in business and finance, New Jersey: Prentice-Hall.

Zadeh, L.A. (1965). "Fuzzy set". *Information and Control*. Vol. 8, No. 3, pp.338–353.

10. Appendix A

Table 4 Sustainable production indicators (Veleva and Ellenbecker, 2001)

No	Indicator	Goal	Metric
1	Freshwater consumption	Reduce freshwater consumption	Litres
2	Materials used	Reduce materials used	Kilograms
3	Energy use	Reduce energy use	kWh
4	Percent energy from renewable sources	Increase the use of energy from renewable sources	Percent
5	Kilograms of waste generated before recycling	Reduce the amount of waste generated (air, water, and land) before recycling.	Kilograms
6	Global Warming Potential	Reduce greenhouse gas emissions	Tons of CO2 equivalents

Table 4 Sustainable production indicators (Veleva and Ellenbecker, 2001)

No	Indicator	Goal	Metric
7	Acidification potential	Reduce emissions of acid gasses	Tons (or kilograms) of SO2/SOx equivalents.
8	Kilograms of persistent, bio accumulative and toxic (PBT) chemicals used.	Phase-out all PBT chemicals used by the company	Kilograms
9	Costs associated with EHS compliance	Reduce EHS compliance costs	$
10	Rate of customer complaints and/or returns	Achieve zero customer complaints and returns	Rate (e.g., number of complaints/returns per 100,000 products sold)
11	Organization’s openness to stakeholder5 involvement in decision-making process	Increase stakeholder involvement in decision making	Level of openness (1–5)
12	Community spending and charitable contributions as percent of revenues.	Increase community spending and charitable contributions	Percent
13	Number of employees per unit of product/dollar sale	Increase employment opportunities for the local community.	Number
14	Number of community company partnerships	Increase community company partnerships	Number
15	Lost workday injuries and illness case rate (LWDII).	Achieve zero lost workdays as a result of work-related accidents	Rate
16	Rate of employees’ suggested improvements in quality, social and EHS performance	Increase the rate of employees’ suggested improvements	Rate
17	Turnover rate (or average length of service of employees)	Reduce turnover rate (or increase the average length of service of employees	Rate (Years)
18	Average number of hours of employee training	Increase employee training	Hours
19	Percent of workers who report complete job satisfaction	Increase employee wellbeing and job satisfaction	Percent
20	Percent of products designed for disassembly, reuse or recycling	Design all products to be disassembled, reused or recycled	Percent
21	Percent of biodegradable packaging	Use 100 percent biodegradable Packaging	Percent
22	Percent of products with take back policies in place	Increase percent of products with take-back policies	Percent