Measuring Industrial Symbiosis Index Using Multi-Grade Fuzzy Approach

C. Kalyan, T. Abhirama, Neyara Radwan Mohammed, S. Aravind Raj and K. Jayakrishna

Abstract The article reports a research that was carried out to measure the industrial symbiosis percentage of an industrial symbiotic setup utilising multi-grade fuzzy approach. Industrial symbiosis is a subclass of industrial ecology which describes how a cluster of assorted organizations can foster eco-innovation and long-term culture change, create, and share mutually profitable transactions and improve business and technical processes. A symbiosis measurement framework model incorporated accompanied by multi-grade fuzzy approach was developed. Successively, data congregated from the industrial symbiotic setup under study were substituted in this representation, and the improvement areas for symbiosis enhancement of the organization were elucidated. The application of this study reveals that the organization in question was symbiotic. Yet, there was further scope for improvement of symbiosis in the organizational cluster. On utilising, the model represented in this paper indicates that the symbiosis of the organization as well as the actions required to enhance its symbiotic level. This process is bound to accelerate the absorption of the symbiotic attributes of the organizations in Industry 4.0.

Keywords Industrial symbiosis · Symbiotic characteristics · Symbiosis percentage assessment · Fuzzy method M

1 Introduction

Every organisation exhaustively utilises its raw material, workforce and cash deposits in order to make finished goods or services with a lot of wastes and by-products. What if wastes and by-products of a company transform into raw material for another? As coined by Chertow, industrial symbiosis engages traditionally separate industries

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in relatively close proximity to gain a competitive advantage involving physical exchange of materials, energy, water, and/or by-products through collaboration [1]. In this research, symbiosis of an industry was evaluated through the symbiotic characteristics or aspects like environmental benefits, policy benefits, management benefits, economic values, and customer feedback of an organization. In order to overcome the drawbacks of conventional methods, this study applies multi-grade fuzzy approach to evaluate symbiosis. To attain the given objectives, the study has been conducted by evaluating the symbiosis percentage of a tire-manufacturing organization.

2 Literature Review

Lombardi et al. discuss and redefine various interpretations of IS. Furthermore, this study posits that geographical proximity of industries is not necessarily sufficient or is a singular focus on physical resource exchange in Industry 4.0 [2]. Laybourn et al. discuss how National Industrial Symbiosis Program (NISP) of UK initiated by International Synergies Limited in 2003 had been successful in making multiple government and private bodies symbiotic all across Europe, Asia, Africa, and North and South America [3]. Desrochers takes an historical approach on how industrial symbiosis was nothing new and that it has existed during the Victorian times. It also sheds light on the reasons why industrial symbiosis did not take the limelight then and why it did in recent times [4]. Mantese et al. take the virtues of industrial symbiosis into the field of product development. They introduce and explain the concept of Design for Industrial Symbiosis (DFIS) [5]. Jensen in his study explored influences of industrial diversity geospatially and its effect on the working agreements of industrial symbiosis. The industrial diversity of a given geographical area in this paper was the primary driver behind how far a material travels from its point of origin to its point of reuse [6]. Ntaisou et al., in their study, shed light on various sustainability criteria, how geographic proximity and spatial principles affect the designing of an industrial park. They have also included a case study of sitting and designing a business park in Greece [7]. Novak et al., in their book, provide a formal theory of fuzzy logic. Generally, it is used to take care of the concept of partial truth, where the values range between entirely true and entirely false [8]. Cintula et al., in their article, explain and extoll about the virtues of fuzzy logic and its uses from an academic perspective with various real-world examples and case studies [9]. Vinodh et al. in his article assess the sustainability of an organization using multi-grade fuzzy approach with various sustainability enablers, criteria, and attributes mapped out [10].

2.1 Conceptual Model of Symbiosis Evaluation

As shown in Table 1, the conceptual model for industrial symbiosis is viewed from five perspectives namely environmental benefits, policy benefits, management benefits, economic values, and customer feedback. The proposed model of MGFA consists of two levels for the symbiosis evaluation. First level consists of the five symbiosis aspects (S_i) and the second in total deals with 25 symbiosis criteria (S_{ij}).

Table 1 Conceptual model for symbiosis evaluation

Symbiosis aspects (S_i)	Symbiosis criteria (S_{ij})
Environmental benefits	Recycle of waste resources
	Design for environment
	Solid waste management
	Utilization ratio of raw material
	Energy recycling
Policy benefits	Government policy
	Stakeholder involvement
	Voluntary agreement
	Existing policy
	Expected policy
Management benefits	Market structure management
	Enterprise management
	Waste management
	Information sharing
	Human resource management
Economic values	Growth rate
	Impact of R&D in GDP
	Capital investment
	Revenue generated
	Price and quantity control
Customer feedback	Customer satisfaction
	Serviceability
	Reverse logistics
	Quality control and assurance
	Customer acquisition

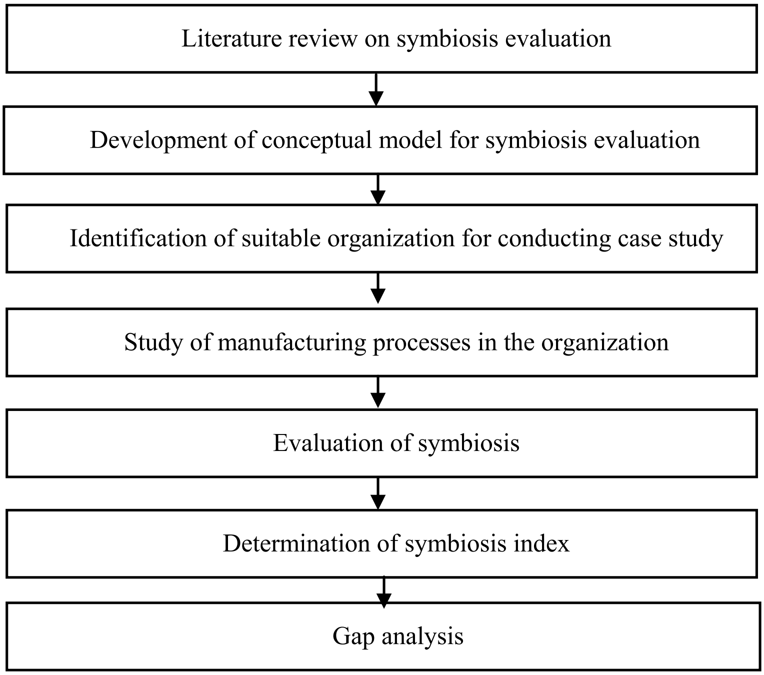

Fig. 1 Methodology

3 Methodology

As shown in Fig. 1, the methodology of this study initiates with a thorough literature review on symbiosis evaluation. Followed by the development of a conceptual model for carrying out the evaluation, identification of a case organisation to measure its industrial symbiosis using multi-grade fuzzy approach and finally determining its symbiosis index and summarising the results and key observations made.

4 Case Study

4.1 Case Company

The case company in this study is taken to be a tire-manufacturing company in Tamil Nadu. Hereafter, it is referred to as ABC Tire Company.

4.2 Evaluation of Symbiosis with the Help of Multi-grade Fuzzy Method

Multi-grade fuzzy approach was used in this study to measure the industrial symbiosis index to overcome the drawbacks of conventional crisp approaches [10]. Measurement of industrial symbiosis index using multi-grade fuzzy approach is a new contribution to the theory.

Symbiosis index of an organization, depicted by the variable S, is the matrix product of the overall assessment factor R and the overall weight W. The equation for symbiosis index is

$$S = W \times R \tag{1}$$

Five experts on a scale of 1–10 have performed the evaluation, where '1' represents 'extremely un-symbiotic' and '10' represents 'extremely symbiotic.' The experts have rated the symbiotic performance as shown in Table 2 for the criteria and aspects mentioned in Table 1.

4.3 Symbiosis Evaluation for the First Criteria

The calculation for the 'environmental benefit' criterion is as follows:

The weights concerned with 'environmental benefit' criterion are

$$W_1 = (0.1, 0.4, 0.15, 0.15, 0.2) \tag{2}$$

Evaluation vector related to 'environmental benefit' criterion is

$$R_1 = \begin{bmatrix} 8\ 6\ 8\ 6\ 9 \\ 7\ 9\ 8\ 5\ 6 \\ 6\ 8\ 9\ 5\ 7 \\ 9\ 6\ 6\ 6\ 7 \\ 5\ 7\ 9\ 7\ 9 \end{bmatrix} \tag{3}$$

Index related to environmental benefits is given by

$$S_1 = W_1 \times R_1 \tag{4}$$

$$S_1 = (6.85, 7.6, 8.05, 5.65, 7.2) \tag{5}$$

Using the same principle, the index related to the rest of the symbiosis criteria has been derived

Table 2 Matrix of evaluation vector and weights provided by experts

S_i	S_{ij}	$E1$	$E2$	$E3$	$E4$	$E5$	W_i	W_{ij}
S_1	S_{11}	8	5	8	6	9	0.10	0.3
	S_{12}	7	9	8	5	6	0.40	
	S_{13}	6	8	9	5	7	0.15	
	S_{14}	9	6	6	6	7	0.15	
	S_{15}	5	7	9	7	9	0.20	
S_2	S_{21}	6	7	7	5	7	0.20	0.05
	S_{22}	7	9	8	9	9	0.30	
	S_{23}	6	6	9	9	6	0.10	
	S_{24}	5	7	8	9	8	0.20	
	S_{25}	5	7	9	9	6	0.20	
S_3	S_{31}	8	5	8	8	7	0.25	0.2
	S_{32}	7	8	7	7	6	0.25	
	S_{33}	7	5	7	7	8	0.20	
	S_{34}	8	8	5	7	8	0.15	
	S_{35}	5	9	8	7	5	0.15	
S_4	S_{41}	9	9	7	5	6	0.20	0.2
	S_{42}	7	8	9	7	6	0.10	
	S_{43}	8	9	7	7	6	0.30	
	S_{44}	8	9	5	5	6	0.20	
	S_{45}	6	7	9	7	7	0.20	
S_5	S_{51}	5	5	6	8	9	0.30	0.25
	S_{52}	7	9	9	7	6	0.15	
	S_{53}	9	9	5	7	5	0.15	
	S_{54}	8	9	7	6	9	0.20	
	S_{55}	8	6	7	9	9	0.20	

$$S_2 = (5.9, 7.5, 8.1, 8.2, 7.5) \tag{6}$$

$$S_3 = (7.1, 6.8, 7.1, 7.25, 6.8) \tag{7}$$

$$S_4 = (7.7, 8.5, 7.2, 6.2, 6.2) \tag{8}$$

$$S_5 = (7.1, 7.2, 6.7, 7.5, 7.95) \tag{9}$$

4.4 Symbiosis Evaluation for the Secondary Criteria

The symbiosis index of ABC tire-manufacturing organization has been calculated to be:

Overall weight

$$W = (0.3, 0.05, 0.2, 0.2, 0.25) \tag{10}$$

Overall assessment vector is given by Eq. 11

$$R = \begin{bmatrix} 6.85 & 7.6 & 8.05 & 5.65 & 7.2 \\ 5.9 & 7.5 & 8.1 & 8.2 & 7.5 \\ 7.1 & 6.8 & 7.1 & 7.25 & 6.8 \\ 7.7 & 8.5 & 7.2 & 6.2 & 6.2 \\ 7.1 & 7.2 & 6.7 & 7.5 & 7.95 \end{bmatrix} \tag{11}$$

Symbiosis index

$$S = W \times R \tag{12}$$

$$S = (7.085, 7.515, 7.355, 6.67, 7.1225) \tag{13}$$

$$S_{\text{avg}} = 1/5(7.085, 7.515, 7.355, 6.67, 7.1225) \tag{14}$$

$$S_{\text{avg}} = 7.1495 \tag{15}$$

5 Results and Discussion

The industrial symbiosis index, which was calculated by utilizing multi-grade fuzzy approach, was 7.15. It indicates that the ABC tire-manufacturing organization is suitable for symbiosis. There is still scope for improvement of the symbiosis index in following areas.

- Government policy
- Revenue generated
- Customer satisfaction
- Waste management
- Human resource management
- Utilization of raw materials.

Table 3 Feedback from experts

Symbiosis aspects (S_i)	Likert scale rating of range 0–10					Mean response
	$E1$	$E2$	$E3$	$E4$	$E5$	
Environmental benefits	7	10	7	7	10	8.2
Policy benefits	9	8	10	7	8	8.4
Management benefits	7	7	10	9	9	8.4
Economic values	10	8	7	9	10	8.8
Customer feedback	7	8	10	8	10	8.6

5.1 Validation

In order to deem this study valid, a survey has been conducted and feedback from the experts was collected on the symbiosis aspects. The responses are recorded on a Likert scale of 0–10, and the results are as follows.

As shown in Table 3, the mean responses are 8.2 at the minimum for environmental benefits and 8.8 at the maximum for economic values. The mean response feedback points toward the possible implications and utilization of multi-grade fuzzy method in order to evaluate industrial symbiosis.

5.2 Industrial Implications

The implications of this study are reported in sustainability viewpoint, i.e., based on the triple-bottom line of sustainability (economic, environmental, and social) [11].

5.3 Economic Implications

Industrial symbiosis has huge economic advantages. The costs can be cut for the industries, which utilize the by-products and wastes of other industries as raw materials, as well as increase the revenue for the industries by selling their wastes and by-products at a price.

5.4 Environmental Implications

When multiple industries come together to be symbiotic, they make up an industrial corridor. This lets them cut down on the environmental impacts like reduced transportation.

5.5 Social Implications

Industrial symbiosis helps in an inclusive growth of the industries with sustainable future as a common goal, providing higher job opportunities and good relations between the industries in this extremely competitive Industry 4.0. It inculcates moral and ethical values to its employees as well as its partner industries providing a vision to grow and succeed.

6 Conclusion

The increased competition in Industry 4.0 has forced companies to collaborate and maintain good relations by being symbiotic. The contemporary or traditional industries are making an effort to evolve in order to survive be it by acquiring, merging, or collaborating. The symbiosis evaluation of ABC tire-manufacturing industry implies that ABC is symbiotic but still there is further scope to improve in the aspects of government policy, revenue generated, customer satisfaction, waste management, human resource management, and utilization of raw materials. In these perspectives, this study reports the measurement of industrial symbiosis index of a tire-manufacturing company using the conceptual model developed. The measurement indicates that the organization is symbiotic in nature. On the improvement of the identified week areas, symbiosis of the organization could be improved which enables the organization to attain complete symbiosis under a circular economy.

6.1 Limitations and Future Research Directions

This study uses multi-grade fuzzy method for this study to evaluate symbiosis in a single industry. Advanced fuzzy logic methods can be utilized to evaluate for multiple industries. Further research can also be toward using different methods similar to multi-grade fuzzy logic.

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