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Sustainability assessment framework for manufacturing sector – a conceptual model

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Abstract

There is lack of structured methodological frameworks to assess sustainability of manufacturing organizations. The effective sustainability assessment is a challenge for manufacturers, researchers and governments. This paper proposes a hierarchical framework for sustainability assessment of manufacturing organizations. The proposed framework consists elements/performance measures to improve and assess the organizational policies, people, products, processes, and performance from triple bottom line perspective. The sustainability assessment captures the whole supply chain of the organization including end of life strategies for products. The framework has been tested using data from a cement manufacturing organization. A model of framework performance measures/elements has been developed using interpretive structure modelling (ISM).

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Keywords: Sustainability, Framework, sustainability assessment, elements, performance measures,

1. Introduction

The global scenario of natural resource depletion; and environmental, economic, and social imbalance is motivating organizations and individuals to incorporate sustainable practices in various aspects. Sustainability has been widely accepted as an essential feature of human activities. However, only a little guidance is available for its practical implementation and assessment. From the overview of various definitions discussed in the study of Lee and Lee [1], it has been observed that the consensus on sustainability in manufacturing is still not developed. In the past, the term was mainly environmentally oriented, i.e. sustainability as the quality to sustain the environment [2]. However, in current literature, sustainability is defined with three dimensions: environmental, social and economic, sometimes adding a fourth one, technology [3]. Sustainable manufacturing can be considered as one of the most important issues to address, for pursuing the big picture of sustainable development (SD) because of the following two reasons. First taking into account the social importance of manufacturing in our societies and second, considering its huge impact on energy consumption, on the use of physical resources, and emissions to the environment [4], which are also in the aim of SD goals of UN, especially people and planet motives [5]. In the concept of SD different aspects cultural, economic, social, natural environments etc. are added for the integrity of nature and society [6]. Organizations are implementing various strategies and best practices for making the business environmentally efficient, socially sufficient and economically viable. Hence, it is suggested to manufacture the product using bearable production processes through sustainable manufacturing practices. A study including all the aspects of sustainability and incorporating existing best practices is imperative [7]. Use of sustainable resources and processes, increased efficiency and reduced environment impact are core needs for engineering sustainability [8]. Various research studies have provided analytical assessment of widely used sustainability initiatives for manufacturing industry to holistically support

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the topic of sustainability [9], [10]. Appropriate performance measures supported with suitable indicators are essential to assess the sustainability of manufacturing organizations. Structured frameworks using these performance measures can be a handy tool for practitioners to assess the sustainability of their business models. Also, the implementation of corrective actions could be driven by such frameworks. The definition of a structured framework is essential to communicate company's performances to external stakeholders.

This study aims to develop a five level hierarchical conceptual framework for sustainable manufacturing. Proposed model is self-explanatory to achieve sustainability from policy level to sustainability performance measurement level. This with an aim to change as minimum as possible with large impact with a top-down approach [11]. In the next section, a brief discussion of sustainability in manufacturing is provided. The idea of proposed framework is visualized in section 3. The framework proposed here is empirically tested in the cement industry of India using survey methodology as shown in section 4. A model of 19 elements/performance measures including three dimensions of sustainability performance measurement has been developed using interpretive structural modelling (ISM). The section 5 is comprised of concluding remarks and future scope.

2. Literature review and methodology

Sustainability is both ancient and newer concept, its importance is rising in day to day working environment and culture. Manufacturer and consumers are willing to orient towards sustainability and sustainable products. But still the academic and practitioner community has not reached at common consensus on the definition of SD and sustainable manufacturing. The definition provided by the Brundtland commission is still valid in case of sustainable development [12]. In case of sustainable manufacturing, the definition provided by the Department of Commerce is widely accepted by many academicians and researchers [2], [13].

The literature review carried out for frameworks and initiatives on sustainability assessment shows that, several practices were employed by research community to assess sustainability in manufacturing organizations. The commonly used practices or tool for sustainability assessment are balance scorecard method [14-15], sustainable value stream mapping [16], use of multi criteria decision making [17], indicator based assessment [17-18], software and mathematical modelling of sustainability assessment [17], [20]life cycle analysis [21-22], product service system [23], sustainability index [24- 25] etc.

According to Gasparatos [26], sustainability assessment tools are classified in three main categories – monetary tools, biophysical tools, indicators tools, and various sub-categories. The study suggest to incorporate a well-balanced 'indicator tool'. Which is defined as combination of monetary tool and biophysical tools, and which can present the diversified value orientation of stakeholders along with the combination demanded challenges. Further, it has been observed from the existing research studies that sustainability assessment tools are used heterogeneously and a well-balanced 'indicator tool' is missing.

It was found from the above literature that the articles addressing sustainability, sustainability assessment, sustainable performance measurement are dealing with particular practice or tool. Hence, an integrated framework for sustainability assessment including product life cycle engineering, green and lean manufacturing, supplier and supply chain management, employees and customer, end-of-life strategies etc. is missing. The above literature review implies that these techniques are used for sector specific or organization specific conditions and dealing with limited indicators of sustainability.

The present study proposed a five level hierarchical framework for sustainability assessment in manufacturing industry. Fig. 1. shows the research methodology adopted in the present study. Next section of the study discusses the proposed conceptual framework and also discusses the similar and existing research work of hierarchical frameworks.

3. Proposed conceptual framework for sustainability in manufacturing

The research community addresses sustainability as a complex problem and many dimensions/elements should be considered for all-inclusive coverage of sustainability in manufacturing sector [4], [27]. The inclusiveness of best practices and manufacturing aspects can be seen in form of

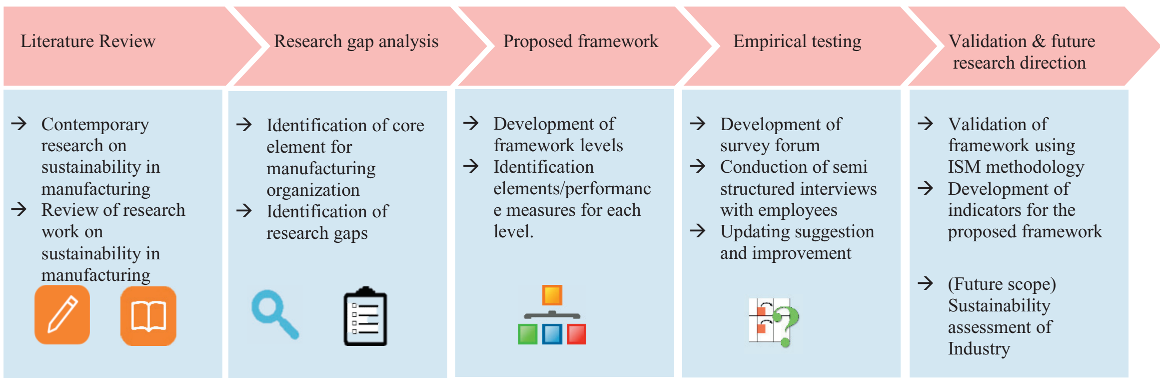


Fig. 1. Research methodology used in the study

research articles aiming to achieve sustainability in manufacturing sector [31-32]. Batterham [30] found that sustainable development is complex and required to be addressed at different levels. A five level hierarchical framework is presented in the study as: global objective, industry strategy, enterprise targets, specific projects, and individual actions/measured outcomes. Whereas, Shields et al. [31] claims that hierarchies are complex systems and developed on asymmetrical relationship among the sets. Another study by Veleva and Ellenbecker [19], presented a five level hierarchical framework for sustainable production starting from facility compliance, facility use, facility effect, supply chain and life cycle, and at top sustainable system level [19]. Mittal and Sangwan [32] also developed five level hierarchical model using ISM for the barriers of environmental conscious manufacturing. It is observed that lack of information and awareness, top management commitment are the important barriers for level 1 and level 2 respectively. The hierarchy based models discussed in literature studies address the sustainability either in general or for a specific industry [33-34]. However, sustainability assessment and improvement models for manufacturing sector has gained a little attention only.

This study has also incorporated the hierarchical approach to provide a novel framework for sustainability assessment. Hierarchical approach is selected in the study because it is able to handle complex interactions between elements/performance measures, industry, society, and ecosystems etc. The hierarchical models can tackle these relationships meticulously because they have their roots in system theory [30]. Initially Maslow's hierarchy model was developed to illustrate human needs. The model was further modified to be used in manufacturing organization [35]. The hierarchy models clearly elicit that basic level needs should be satisfied to move forward [35]. A sustainability cone based model approach has been incorporated Rodger et al. [11], with main focus on product and production with inclusion of life cycle stages at early design phase.

The three main objectives to formulate a framework for sustainability in manufacturing are: inclusion of full scope of sustainable manufacturing consisting all drivers and barriers, reflect the relationship among manufacturing and global environment (as defined by Rockström et al. [36]), and allocate absolute targets [11]. Whereas a study by Bey [37] suggests for consistently breaking down the high-level target into low level targets. The target proposed in this paper is to assess and improve sustainability in manufacturing sector. When, considering this as a main aim, the study divided it into five levels of the framework which are discussed later in this section.

The first level of the proposed framework belongs to assessment of organizational "Policies", for organizational assessment for its dedication towards sustainable development. Policies and drivers influence the activities of facility managers. Sustainability policies of the organization directs the organization to pursue sustainability practices, and differences in sustainability practices can be easily visualized in policies, which is further influenced by multiple stakeholders of the company [38].

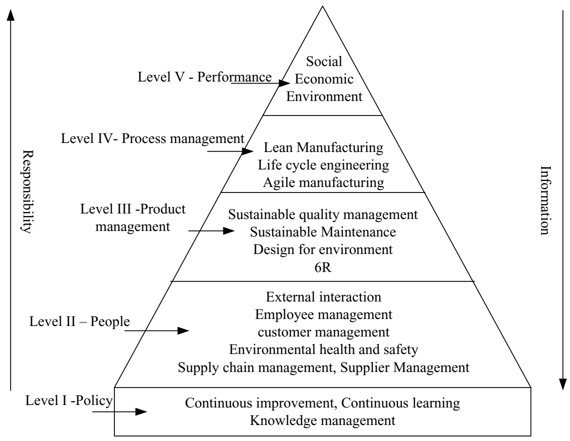


Fig. 2. A five hierarchical conceptual framework

The second level give raise the supposition of "People" involvement. The people are necessary elements for any organizational activity and from the foresight of social sustainability, all stakeholders affected by organization activities should be included in sustainability assessment model. The seventeen SD goals of UN agenda 2030, also predominantly focus on people [5].

The third and fourth level of the framework are discerned as "Product management" and "Process management". The product management is included to deliver sustainable products to society and by incorporating bearable processes at next level process management. In the hierarchy product management is kept a low level because processes are designed according to the product requirement. The product management is aimed to address issue of product design [39], sustainable maintenance [40], 6R [41] etc. Whereas in the process management inclusion of lean, green and life cycle engineering can assist the production processes to be more eco-effective over eco-efficient [42].

At the top level "Performance" is kept to assess overall sustainability based on three dimensions, using appropriate sustainability assessment indicators which also involve the influence of lower level elements. The foresight here in this model is that first four level of the frameworks are to support manufacturing organizations for improving sustainability of the elements/performance measures of defined levels. The top level includes sustainability dimensions, using appropriate indicators sustainability assessment can be performed for the industry for each dimensions. A sample list of such indicators is provided in the study for better understanding as shown in Table 1. The sample list clearly states that the indicators used at level five of the framework for sustainability performance measurement, are also assessing the effects of framework elements of different levels indirectly. Therefore, improvement in sustainability using these elements can leads to overall sustainability of the organization. The sample list contains both quantitative and qualitative indicators for sustainability assessment. These sample indicators are mapped across the sustainability dimensions and four levels of proposed conceptual framework. The basis for assessment is the performance measures/elements incorporated at the below four levels. The elements/performance measures selected are briefly described for more clarity in Table 2.

Table 1. Sample list of indicators for sustainability performance measurement

S. No.	Indicator	Dimension	Levels: Policy	People	Product	Process
1.	Total amount of energy used	En.	√		√	√
2.	Environmental policy	En.	√			
3.	Hazardous raw material used per kg of product	En.			√	√
4.	Design for life cycle	En.		√	√	√
5.	Total hours of employee training per year	S	√	√		
6.	Percentage of employee provided with housing	S	√	√		
7.	Investment on employee training	E	√	√		
8.	Investments in research and development	E	√		√	√

4. Empirical testing of framework in Indian Cement industry

Content validity and possible use of the proposed model has been carried out using industry persons from the cement manufacturing sector of India. A online survey questionaaire is developed to assess the importance of framework and its elements. The online survey insturment followed by a regular telephonic conversation with the respondents of the cement industry on India. The online survey instrument was forwarded to the various cement organization via email. A total number of 33 respondents replied for the same. The average experience of the respondents was more than 10 years and the designation of the respodents varied from Engineer – Deputy manager – General manager. In the analysis respodents were asked to about the level and respective elements. The repondent has to selected a reply for level and element: first they have to say if any of level require any changes, second if the elements selected for the respective level is correct, and if any other element is required at the respective level. Afterwords, respondents were asked for the importance rating of all the selected elements on a five point scale. Few of the repondents denied for social performance as a assessment measure, and very few were also against the follwing elements: knowledge management, supply chain and

Table 2. Small description of framework elements/ performance measures

Level	Factors	Visualization of sustainability
Policy	Continuous improvement (CI)	It can support rapid improvement in sustainability and leads to deliver sustainable products in a long-term goal. Sustainability indicators needs a continuous improvement.
	Continuous learning (CL)	Sustainability itself is an ongoing/continuous learning process, and organizational learning is an important aspect of balance scorecard.
	Knowledge manage-ment (KM)	Knowledge has become one of the important driving forces for success in business, lack of knowledge can be a barrier for environmental improvement, and knowledge management can be a basis for sustainability framework.
People	External interaction (Ex. Int.)	It is the way in which the business interacts with the external stakeholders and systems. Research community suggests that to overcome the weak sustainability, we should address the external interaction with environment and social system.
	Employee manage-ment (EM)	It covers various aspects employee training, pride, allowance, team spirit, autonomy, motivation, involvement etc. which help the organizations growth and analyse the level of sustainable operation management.
	Customer manage-ment (CM)	It describes the organizations approach to manage current and future customers by making policy, technical support, improve product quality using the sustainable technology.
	Environ-ment health and safety (EHS)	EHS is responsible in every company for environmental protection and occupational health and safety at workplace. Environmental, health and safety is getting importance among the organizations and researchers with increase in cost of environmental operations, market, peer pressure etc.
	Supply chain manage-ment (SCM)	It basically addresses the material flow from raw material to finished goods, then to the customer and end of life in the context of manufacturing sector. In terms of sustainability in SCM incorporate environmentally and economically viable practices through the product life cycle (cradle to cradle) by parallel balancing of social sustainability.
	Supplier manage-ment (Sup. M)	It is found as important aspect by the research community to address the pre-chain stakeholders, to avoid the weak sustainability adoption, and to achieve sustainable production by supplier motivation. Suppliers are important in context of environmental activities and waste by products and hence, for sustainability in manufacturing organization.
Product management	Sustainable quality manage-ment (SQM)	It ensures that the organization, product, and service is consistent in all three dimensions of sustainability viz. environmental, economic and social'. Further quality management has a positive effect on environmental performance of the sustainability and sustainable quality management is a practical measure.
	Sustainable main-tenance (SMM)	It can be defined as "all required processes for ensuring the acceptable assets condition by eliminating negative environmental impact, prudent in using resources, concern for the safety of employees and stakeholders, while at the same time economically sound".
	Design for environ-ment (DOE)	This approach aims to design and develop product, process and services with reduced environment and human health impact throughout its whole life cycle.
	6R	The 6R concept actually represents the terminology: reduce, reuse, recover, redesign, remanufacture, and recycle.
Process management	Life cycle engineering (LCE)	The LCE is associated with assessment of economic and environmental impacts of the product/process life cycle under the defined boundary conditions.
	Agile Manu-facturing (AM)	It is seen as a promising concept to face the continuous change in competitive global market. It is well known for its advantages *viz* cost reduction, flexibility, customer response, delivery conditions and good quality.
	Lean manu –facturing (LM)	It is oriented towards reduction of waste to increase productivity and performance of a manufacturing process. Selecting the Lean manufacturing as an framework element will at the end lead to sustainability.
Performance	Social (S)	Social sustainability refers to human wellbeing. In terms of social sustainability in manufacturing organizations, it refers to community investment and development, employee motivation, customer relation, employee retention etc.
	Economic (Ec)	Economical sustainability assesses profitability, sales, return on investment (ROI), value added, taxes, fines and penalty etc. The quantitative economic data are found as better options to know how a business organization is performing in terms of market share, profit, profit vs. productivity, ROI, etc.
	Environ-mental (En)	Environmental sustainability is about the ecosystem wellbeing. It is defined as "condition in which the ecosystem maintains diversity and quality, its capacity to support all life, and its potential to adapt to change to provide future options"[43].

supplier management, employee management, external interaction, 6R concept/methodology, design for environment, life cycle engineering, lean and agile manufacturing. However, the number of respondents in favour the proposed framework and elements were very high. The high number of respondents wished that, the positioning and level distribution is good and not many changes were asked. Few of respodents comments are as follows: "framework is excellent, work life balance is required, and inclusion of complaince to legal requirement". The overall response for the proposed framework was very positive, and respondents found it as good tool for sustainability improvement and assessment, the final framework model is shown in Fig. 2. Further, the proposed model has been validate using imperative structured modelling (ISM) technique as described in 4.1.

4.1. Steps to carry out ISM

To provide a better understanding of elements/performance measures proposed in the proposed framework, an interelationship, hierarchy of importance and interventional level classification are important. Following are the steps to carry out the ISM:

I. In total 19 elements/performance measures selected from literature
II. A contextual relationship is established among the elements/performance measures by a team of expert
III. A structural self-interaction matrix (SSIM) is derived for the selected elements.
IV. Initial reachability matrix is developed from SSIM by converting it to a binary matrix by substituting V, A, O, and X by 1 and 0 as per situation. Which are as follows:
    - If the (i, j) entry in SSIM is V, then the (i, j) entry in reachabilty matrix becomes 1and the (j, i) entry becomes 0.
    - If the (i, j) entry inSSIMis A, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.
    - If the (i, j) entry in SSIM is X, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.
    - If the (i, j) entry in SSIM is O, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.
V. Initial reachability matrix is checked for transitivity (which is defined as "a contextual relationship that if element a is related to corresponding element B, B is related to C, then A is related to C") [44].
VI. To maintain the brevity of the article the final reachability matrix has been shown in Table 3 of the paper, and the final ISM model has been shown in the Appendix A.

5. Conclusions and future scope

This research work proposed a five levels conceptual framework for assessment of sustainability in manufacturing. The definition of these five levels provides an idea of manufacturing excellence as well as sustainability in manufacturing sector.

Table 3. Final reachability matrix

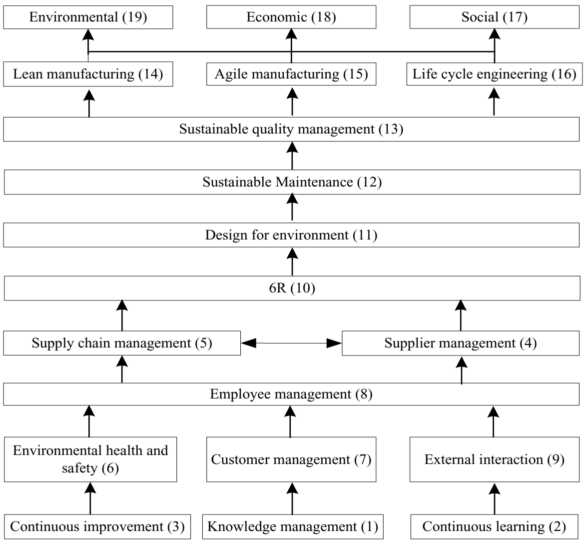
S. No.	Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Driving
1	KM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
2	CL	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
3	CI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
4	EHS	0	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	15
5	CM	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
6	Ex. Int.	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
7	EM	0	0	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	14
8	Sup. M.	0	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	13
9	SCM	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	13
10	6R	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	10
11	DOE	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	1	1	9
12	SMM	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	8
13	SQM	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	7
14	LM	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	1	1	6
15	AM	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	6
16	LCE	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	1	6
17	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
18	Ec.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
19	En.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3

The elements/performance measures of the framework are derived from the literature review and briefly discussed to describe their purpose in proposed framework. Managers and practitioners are liberated to select or eliminate the elements of framework according to the suitability of industry and product portfolio.

The study also briefly discussed various type of practices for sustainability assessment and improvement. Defining indicator sets for the proposed conceptual model is not the aim of this research work, although it is the future research direction to establish an indicator repository for sustainability assessment of manufacturing sector. The proposed framework also provides suppleness to managers and decisions maker to develop their own indicator based on the philosophy and terminology explained here by encouraging the stakeholders' participation.

Further the framework has been tested for improvement and usages in Indian cement manufacturing industry. The framework has been found as an important tool for sustainability. This study limits itself to the truth that some of the aspects presented in the framework leads to improve and support assessment of same impact at different level. However, it is believed that above mentioned limitation is not applicable for the entire manufacturing sector and thus, make the framework generalized for manufacturing organizations.

Appendix A: ISM model of the proposed framework



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