Application of Structural Equation Modelling To Analyse the Environmental Impact of Sustainable Manufacturing Implementation

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Abstract

Sustainable Manufacturing (SM) has become a primary concern in broader perspective of Supply Chain Management (SCM) with the urgent need to address environmental impact of manufacturing activities. There is a need of integrated and more comprehensive approach for the implementation of SM with due importance to manufacturers' perceptions towards the decision making issues related to 'manufacturing' and 'technology' domains. The paper addresses this need with primary focus on SM implementation with a new framework based on domains of 'Manufacturing and Technology, Environmental, Social, Economical'. Partial Least Square – Structural Equation Modelling (PLS-SEM) approach has been used for the analysis of empirical data collected from 72 engineering manufacturing industries from India. The model fit analysis revealed quite satisfactory results for 'manufacturing and technology' domain in addressing environmental concerns of their activities and it revealed a need to enhance the focus on social domain related activities. Authors expect that this study will provide wide openings for the application of SEM model for the analysis of environmental issues to enhance SM implementation in engineering manufacturing industries, in various geographical regions across the globe.

Keywords*: Environmental; PLS-SEM; Structural Equation Modelling; Supply Chain Management; Sustainable Manufacturing*

1. Introduction

Supply Chain Management (SCM) and it's one of the major concerns - 'Sustainable Manufacturing (SM)' [1] have been gaining ever increasing demand in prevailing conditions of intense competition. Manufacturing industries have realised the need of addressing sustainable supply chain management (SCM) practices for reducing negative impacts of their production and consumption processes on the environment [2]. The influence of sustainable SCM and pressures to adopt sustainable practices has been ever increasing [3], [4]. With this, there has been an intense need to address in house issues of the manufacturing plant as well as allied external issues by offering due importance to production and consumption related issues in decision making. In spite of adoption of advanced technologies, manufacturing processes result in adverse environmental problems such as acid rain, poisoning of the biosphere, global warming, and a concern about depleted natural resources [5], [6] [7]. This has already been alarming for manufacturing organisations to enhance their concern over sustainable practices in manufacturing for the reduction in adverse environmental impacts of their manufacturing activities, which plays a crucial role in deciding the economies of the industrialised nations [8], [9].

United Nations Statistics Division (UNSD) had organised an international program for a sustainable society in 1992, wherein the need was recognised to address unsustainable life style and their side effects [10]. The same organisation after ten years realised that one of the major elements is to change the unsustainable patterns of production and consumption for a sustainable development. To achieve this, there is a need for further intense research, business models and community initiative [10]. Ref. [11] mentioned in their research that in most of the manufacturing organisations the product development is practiced with cost/profit models followed by delayed concerns on environmental assessment and are not integrated with existing development activities. Ref. [8] and [12] have mentioned in their research that it has become an important factor in the decision making among industrial societies that for the sustenance of manufacturing businesses it is important to recognise the relationship between manufacturing operations and the natural environment. The research in Sustainable Manufacturing (SM) is rapidly developing and crossing disciplinary boundaries [13]. Furthermore, simple to grasp, relevant, easy to practice and

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meaningful information on SM must be available for the organizations and their managers if sustainability is to enhance in manufacturing. Thus, following sections deal with the literature review, proposed hypothesis and discussions on result of analysis.

2. Literature review

For manufacturing organizations, it has become almost inevitable to adopt more efficient approaches and advanced technologies [14] for enhancing their sustenance in heavy competition. These enhancements can, in part, be provided with the effective and efficient consumption of resources [8] for incorporating sustainability in manufacturing.

Ref. [15] provided a review of literature on sustainable SCM analysing 191 papers from 1994 to 2007 and proposed a conceptual framework. Authors mentioned future scope to study different domains of sustainability with integrated approach to understand their interrelationships and concluded their study by emphasizing on the need of sustainability over a range of issues in SCM by looking at a longer span of the supply chain. During the research study of ref. [16], the results of empirical analysis revealed that environmental, economic and social aspects only are not sufficient to cover the entire concept of sustainable SCM and there is a need to address the aspects such of operations, stakeholders, supplier management, flexible technology, etc.

However, the adoption of sustainability in manufacturing is a huge challenge for organizations since most of them are not aware of how to utilize the enablers and mitigate the effect of barriers of SM [17]. The literature review indicates that study covers the principles for making manufacturing more sustainable but there is little, if any, practical guidance on the application of these principles [18], [19]. U.S. Department of Commerce has defined SM as 'the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound' [12], [17], [18], [20], [21]. Manufacturing industries from developing countries have realised the importance of SM and are attempting to inculcate new approaches about the activities of production and consumption [22]. Organizations those intend to practice environmentally friendly products and operations need to be convinced of economic feasibility and that they can recover costs quickly contributing to competitive advantage rather than suffering a burden [23]. Very few quality reports are available on levels of SM activities exercised by the manufacturing organizations [24]. The challenges of sustainability are required to be addressed from manufacturer's point of view [13] while analyzing manufacturing facilities, infrastructure supporting the manufacturing operations and manufacturing practices. With due consideration to discussions so far, following Table-1 compiles the literature reviewed to highlight the research gap for further study.

Table 1: Compilation of research papers for identifying the research gap.

SN	Major gap for SM implementation	References
1.	Development of Standard/comprehensive reference model or systematic approach for SM	[1], [7], [13], [16], [17], [19], [25], [26], [27], [28], [29], [30]
2.	Identifying and addressing proper critical variables / factors	[5], [7], [9], [17], [26], [31], [32], [33], [34], [35], [36]
3.	Need of empirical studies for the implementation of SM with different/ developing countries	[6], [19], [33], [37], [38], [39]
4.	Different qualitative/ quantitative approaches for SM implementation like SEM, MCDM/ MODM*, etc.	[29], [33], [38], [40], [41], [42], [43]
5.	Lack of guidance on SM/ Limited work on integrating product and process design with sustainability	[11], [21], [26], [44]
6.	SM improvement opportunities in view of manufacturer/ manufacturing operations	[13], [45]
7.	Less work on sustainable production-consumption/ operations management	[19], [22], [31]
8.	Research to improve understanding of SM; enhancing considerations of technology	[1], [12], [46]
9.	Need to enhance /Less focus on effective technologies, manufacturing flexibility	[1], [16], [25], [33]
10.	Establishing industry collaboration to enhance and validate indicators for implementations of SM	[5], [20], [26]

* MCDM=Multi Criteria Decision Making, MODM=Multi Objective Decision Making

Ref. [45] proposed a structural model to test the relationship between environmental pro-activity and financial performance of manufacturing enterprises from India and UK. Ref.

[47] developed SEM model with the focus on factors of manufacturing competency and strategic success for automobile manufacturing industry. Ref. [48] used SEM methodology for evaluating and validating environmental performance improvement model for small and medium enterprises in plastics manufacturing sector mentioning the need to move beyond just complying with the environmental regulations and extend product responsibility.

Ref. [30] used SEM for analyzing factors in SM implementation for manufacturing industries in Tamilnadu state, India. In their paper authors raised one vital and genuine question - How a manufacturer can identify tools and techniques and the relevant capabilities and abilities to become sustainable? Interpretive Structural Modelling (ISM) and Partial Least Square (PLS)-SEM has been used by ref. [49] for the analysis of SM factors in Indian auto-component sector from Tamilnadu, India. The study was concluded by saying that manufacturing organizations from auto-component sector need to practice SM to ensure the competitive edge over others as well as there exists structural relationship between the enablers of SM. The nature of linkage between skill levels of employees and manufacturing flexibility and its impact on business performance has been highlighted by ref. [50] with the application of SEM to the data collected from automotive sector of different countries.

Ref. [37] have studied the role of top management commitment and their participation while dealing with institutional pressures affecting the implementation of sustainable consumption and production from the survey of industries in India using PLS-SEM. They concluded by saying that top management commitment mediates between the institutional pressure and the sustainable consumption and production. Ref. [38] attempted proposing World-Class Sustainable Manufacturing (WCSM) framework with PLS approach. Ref. [51] used SEM methodology to analyze the relationship between cleaner production and business performance of Chinese manufacturing industries. Ref. [52] directed their study towards applying SEM for the analysis of relationship between cleaner production, environmental sustainability and the overall organizational performance for the survey data of 298 companies from Brazil. Authors claim that the implementation of cleaner production practices improves the production capacity, flexibility and aspects of health and safety of the employees. A fuzzy logic-ISM hybrid approach has been used by ref. [53], to evaluate the sustainable production indicators (SPIs) on a qualitative level and have mentioned a future scope for applying SEM to test the validity of hypothetical models. Ref. [54] presented the scope of PLS-SEM highlighting its advantages and limitations. The highlights of using PLS-SEM are that it can handle non-normal data and small sample sizes.

This literature review reveals that there is an ample research potential for SEM application to the implementation of SM in manufacturing industries, with a need of standard/comprehensive reference model. Thus, the main problem identified by authors for study is – *To develop a systematic approach for the application of SEM to SM implementation in Indian engineering manufacturing industries to study its environmental impacts with due focus on manufacturing and technology related issues.*

3. Proposed framework, model and Hypotheses

Considering the discussions on literature review from previous sections and current state of dynamic market conditions, the major objectives of the study are –

- To propose a framework for the implementation of SM
- To identify major variables in the implementation of SM with proposed framework.
- To develop a validated PLS-SEM model for the awareness, ease of acceptance and implementation of SM to support the enhancement of sustainability in manufacturing.

With these objectives, there has been a need for relevant considerations beyond three conventional domains while implementing SM. The need to consider additional 'Manufacturing' related activities has been proposed by ref. [7], [29] and [45] whereas ref. [32], [39], [42], [46] have considered 'Technology' domain related variables in their proposed frameworks. Authors of this paper propose following framework (figure 1) for SM implementation, with additional domain of 'Manufacturing and Technology'.

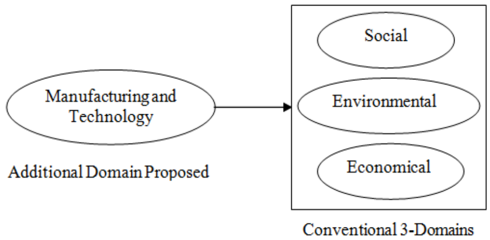

Figure 1: Proposed framework of SM

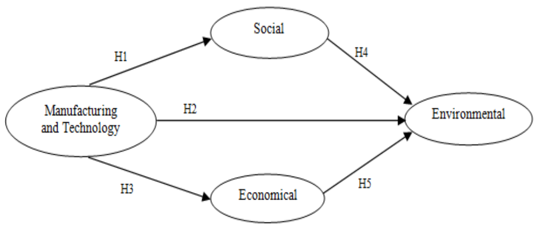

Figure 2: Proposed inner model and hypotheses

Understanding the need of addressing sustainability with integration of vital business concerns, this paper focuses principally on 'manufacturing and technology' related core issues while selecting and grouping the variables under specific domains. Following table 2 provides the list of variables with the citations of the researchers who referred these variables during their study. In addition to this, these variables have been validated by personally interacting with consultants, academicians and experts from manufacturing field, representing various engineering manufacturing industries.

Table 2: Critical Variables in various domains

Variable	**References**
Manufacturing domain	
1. Inventory Quantity	[6], [7], [18], [26]
2. Labour Turnover	[7], [18], [34]
3. Material Waste	[6], [7], [18], [20], [34], [55]
4. Internal Material Handling	[25], [56]
5. Non Value-Adding Time (NVAT) elements	[18], [28]
Technology domain	
1. Technology awareness	[1], [5], [17], [32], [41], [42], [56]
2. Skill/ Expertise	[25], [32], [41], [42], [56]
3.Training and Education	[1], [5], [17], [18], [25], [31], [32], [34], [42]
4. Research and Development	[18], [32], [33], [39]
5. Flexibility	[6], [9], [18], [32], [34]
6. Information and Communication Technology (ICT)	[31], [33], [39], [40], [42]
Social domain	
1. Customer Satisfaction	[5], [12], [18], [34], [39]
2. Employee Satisfaction	[18], [25], [32]
3. Health, Safety, Security of employees	[6], [12], [18], [20], [39]
4. Work culture	[12], [25], [31], [32]
5. Corporate Social Responsibility (CSR)	[5], [12], [18], [32], [34]
Environmental domain	
1. Pollutants	[6], [7], [12], [18], [20], [26], [34]
2. Energy Saving / Generation	[7], [12], [18], [20], [26], [30], [34], [39], [40]
3. Environmental Regulations	[1], [6], [7], [17], [32], [41]
4. Recycling, Re-manufacture, Reuse	[12], [32], [39], [56], [57]
5. Suppliers	[7], [18], [32]
Economical domain	
1. Profitability	[7], [17], [39], [55]
2. Financial Constraints	[1], [7], [17], [30], [32], [39], [41], [42], [56]
3. Government Incentives	[12], [32], [42]
4. Manufacturing costs	[1], [18], [34], [39]
5. Quality Costs	[9], [12], [18], [34]

The proposed inner model (structural model) (figure-2) has four-domains, based on the proposed framework shown in figure-1. Considering the basic objective of this paper, authors define environmental domain as the target endogenous construct to understand the impact of 'manufacturing and technology' related decision making on environmental aspects. With reference to this proposed SEM model, following table-3 gives five hypotheses defined for the study.

Table-3: List of proposed hypotheses

H1	'Manufacturing and Technology' domain activities and Social domain are correlated
H2	'Manufacturing and Technology' domain activities and Environmrntal domain are correlated
H3	'Manufacturing and Technology' domain activities and Economical domain are correlated
H4	Social domain activities and Environmrntal domain are correlated
H5	Economical domain activities and Environmrntal domain are correlated

4. Results and discussions:

After running the model, output from PLS algorithm, is given in following figure-3

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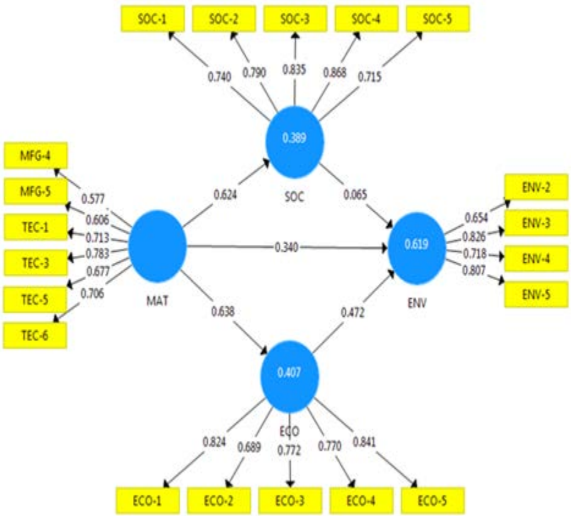

Figure 3: PLS algorithm evaluations for SEM model

The evaluations for outer loadings of the observed variables under different constructs are given in Table-4 (bold values), It shows satisfactory values (>0.7) for most of the variables. But, for four observed variables, the outer loadings are around 0.6 which are retained to study their effect on model fit. The values of Composite Reliability (CR), Average Variance Extracted (AVE) and Chronbach's alpha which indicate construct reliability and validity, are presented in Table-5. These all values, except one, indicate satisfactory levels as compared to recommended values i.e. Composite Reliability and Chronbach'a Alpha values are all greater than 0.7 and AVE greater than 0.5 [58], [59]. The value of AVE for MAT (0.463) is little less than 0.5.

Table 4: Outer loading and cross loading evaluations

	ECO	ENV	MAT	SOC
ECO-1	**0.824**	0.607	0.545	0.598
ECO-2	**0.689**	0.375	0.394	0.469
ECO-3	**0.772**	0.618	0.600	0.563
ECO-4	**0.770**	0.521	0.432	0.564
ECO-5	**0.841**	0.690	0.486	0.620
ENV-2	0.438	**0.654**	0.472	0.363
ENV-3	0.565	**0.826**	0.614	0.608
ENV-4	0.357	**0.718**	0.340	0.191
ENV-5	0.750	**0.807**	0.565	0.572
MFG-4	0.340	0.270	**0.577**	0.371
MFG-5	0.463	0.297	**0.606**	0.407
SOC-1	0.737	0.572	0.599	**0.740**
SOC-2	0.528	0.372	0.451	**0.790**
SOC-3	0.524	0.443	0.462	**0.835**
SOC-4	0.544	0.423	0.484	**0.868**
SOC-5	0.468	0.576	0.424	**0.715**
TEC-1	0.368	0.519	**0.713**	0.386
TEC-3	0.542	0.456	**0.783**	0.600
TEC-5	0.413	0.563	**0.677**	0.297
TEC-6	0.456	0.616	**0.706**	0.451

Table 5: Construct reliability and validity

	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
ECO	0.841	0.886	0.610
ENV	0.750	0.840	0.570
MAT	0.767	0.837	0.463
SOC	0.850	0.893	0.626

Table 6: Discriminant validity – AVE values

	ECO	ENV	MAT	SOC
ECO	0.781			
ENV	0.736	0.755		
MAT	0.638	0.682	0.681	
SOC	0.725	0.619	0.624	0.791

Fornell Larcker criterion and Cross-Loadings are referred for testing discriminant validity. In first case, the AVE of each latent construct should be higher than the constructs highest squared correlation with any other latent construct [58], [59]. These evaluations are shown in Table-6 and satisfy the requirements. The evaluations for cross loadings are given in Table-4 which clearly indicates that the indicator loadings within the construct are higher than those for other constructs, satisfying the validity requirements.

As a part of inner model evaluation, R-square for ECO, ENV and SOC constructs are 0.407, 0.619 and 0.389. R-square values of 0.75, 0.50, and 0.25 for endogenous constructs can be taken as substantial, moderate and weak respectively [58], [59]. All the R square evaluations are moderate in this case as they are near to 0.5 which can be taken as quite satisfactory in manufacturing and technology related decision making. The recommended values for 'F-square' are 0.02, 0.15 and 0.35 for weak, moderate and strong effects. F-square evaluations indicate that MAT→ECO=0.687 and MAT→SOC=0.637 are having strong effect; MAT→ENV=0.163, ECO→ENV=0.245 have moderate effect whereas SOC→ENV=0.136 value indicates little weak effect.

Bootstrap analysis was carried out for 5000 subsamples and the data analyzed is given in Table-7. The values of 't and p', for confidence level of 1 %, indicate that only H4 is not supported by the data where as H1 to H3 and H5 are supported.

Table 7: T-statistics and P-values

Hypothesis	T-Statistics	P values	Hypothesis
H1=MAT→SOC	9.905	0.000	Supported
H2=MAT→ENV	2.842	0.004	Supported
H3=MAT→ECO	9.031	0.000	Supported
H4=SOC→ENV	0.468	0.640	Not-Supported
H5=ECO→ENV	3.160	0.002	Supported

Confidence Level = 1%

It can be inferred from these results that there is a need to enhance the decision making towards social domain for the satisfactory performance of the proposed SEM model while implementing SM to study the environmental issues.

5. Conclusion

Manufacturing industries have realized the need to assess the impact of their activities on the environment while implementing SM as a part of wider span of SCM. But still, literature review indicates that the research activities need to be enhanced in addressing environmental issues related to decision making in manufacturing and technology related activities. This research paper proposes SEM model for studying environmental impacts of implementation of SM under SCM chain by focusing basically on 'manufacturing and technology' related issues as exogenous constructs.

The empirical data is collected from Indian engineering manufacturing industries using 'Survey-Monkey' platform and is analyzed using SmartPLS 3.0 software. Overall performance of the model, based on model fit parameters, reveals that hypotheses H1 to H3 and H5 are supported which indicates that 'Manufacturing and Technology' domain related activities are having better correlation with triple bottom line domains of sustainability i.e. social, environmental and economical. It also shows that hypotheses H5 is supported which indicates that economical domain related activities are also having better correlation with environmental domain. Whereas the model fit analysis does not support hypothesis H4 indicating that social domain related activities do not exhibit better correlation with environmental domain and hence needs more attention. With this, authors infer the need to attend decision making towards social domain related activities to improve the performance towards environment domain related issues.

Authors propose the future scope in studying the mediating and moderating effects for the proposed SEM model. This research work will provide an easy-to-grasp approach for SEM application to SM implementations in manufacturing organizations to study environmental impacts of 'manufacturing and technology' related decision making.

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