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Sustainable Manufacturing Implementation With SMEET Framework For Manufacturing Industries

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ABSTRACT : *In the present era of intense global competition, though considerable research has been carried out in the field of Sustainable Manufacturing (SM), still a lot is required to be done. There is a need of more comprehensive approach for the implementation of SM. This paper aims at addressing this need with primary focus on SM implementation with SMEET framework wherein five domains of '**S**ocial, **M**anufacturing, **E**nvironmental, **E**conomical and **T**echnology' are considered. Proposed Structural Equation Model has been tested using empirical data collected from 72 engineering manufacturing industries from India. The analysis revealed quite satisfactory results for eight hypotheses while remaining five hypotheses were not supported which indicates that there is still an ample scope for improving decision making towards SM implementation and environmental issues in India. Authors expect that this study will provide a systematic approach for sustainable development of manufacturing industries across the globe, through SM implementation.*
KEYWORDS - *Environment, SMEET, Structural Equation Modeling, Sustainable Manufacturing, Technology*

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I INTRODUCTION

Manufacturing activities of the industries across the globe certainly have adverse impacts on the environmental in varying degrees leading to serious consequences by way of acid rain, global warming, etc. leading to depleted natural resources [1]. This situation is increasing the pressures with manufacturers for the adoption of sustainable practices [2, 3] across the supply chain. Manufacturers are almost compelled to exhibit their concern over sustainable practices towards their production and consumption processes to reduce adverse environmental impacts of their manufacturing activities [4]. Adoption of such practices has a dominant role in deciding the economies of the industrialised nations [5, 6].

It was realised during international program on sustainability organised by United Nations Statistics Division (UNSD) by around 2002 that for a sustainable development, manufacturers need to address unsustainable patterns of production and consumption [7]. The need was also felt for intense research, business models and community initiative [7]. For the sustenance in business competition as well as to cater to newer government rules and regulations on environment, manufacturing organisations are trying to correlate their activities to the natural environment [5, 8, 9]. It has been almost mandatory for the firms to adopt sustainability in manufacturing [10]. The research in Sustainable Manufacturing (SM) is developing at a faster pace and crossing disciplinary boundaries [11]. Adoption of sustainable practices in manufacturing is quite challenging for organizations as most of them are not aware of how to address the enablers and barriers of SM [12]. The literature towards research activities in engineering covers the principles for making manufacturing more sustainable. There is very little practical guidance on applying these principles [13, 14]. Relevant, consistent and meaningful information on SM must be available and utilized by the industries for improving the sustainability in manufacturing.

SM as defined by the U.S. Department of Commerce is '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' [9, 12, 13, 15, 16]. Manufacturing organisations are trying to implement SM practices to inculcate new approaches about production and consumption activities [17]. The costs in pursuing environmentally friendly products and operations will be recovered quickly by the organisations and it will offer competitive advantage rather than suffering a loss [18]. The sustainability issues need to be addressed from a manufacturer's point of view [11]. Following Table 1 highlights the research gap in the field of SM implementation with an ample research potential.

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

SN	Major gap for SM implementation	References
1.	Need to develop Standard /comprehensive reference model or systematic approach for the implementation of SM	Kibira [1], Bhanot [10], Despeisse [11], Bhanot [12], Gunasekaran [14], Wu [19], Thanki [20], Chun [21], Vinodh [22], Garetti [23], Zubir [24]
2.	To identify and address critical variables / factors in the implementation of SM	Kibira [1], Dawal [6], Diana [8], Bhanot [12], Kang [25], Dewangan [26], Ghazilla [27], Singh [28], Rusinko [29]
3.	Need of empirical studies for the implementation of SM with different/ developing countries	Gunasekaran [14], Dewangan [26], Dubey [30], Dubey [31], Jovane [32]
4.	Different qualitative/ quantitative approaches for SM implementation like SEM, MCDM/ MODM*, etc.	Chun [21], Dewangan [26], Dubey [31], Trianni [33], Mittal [34], Shi [35], Gungor [36]
5.	Limited work on integrating product and process design with sustainability	Jayal [16], Shankar [37], Kaebernick [38]
6.	SM improvement opportunities in view of manufacturer/ manufacturing operations	Despeisse [11], Sen [39], Haapala [40]
7.	Less work on sustainable production-consumption/ operations management	Diana [8], Gunasekaran [14], Clark [17]
8.	Research to improve understanding of SM; enhancing considerations of technology, manufacturing flexibility	Rosen [9], Bhanot [10], Wu [19], Dewangan [26], Jovane [32], Haapala [40], Chow [41], Severo [42]

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

Considering these discussions on literature review this paper intends to address following questions:

1. What new comprehensive framework can be proposed for SM implementation?
2. What systematic approach can be proposed for SM implementation in engineering manufacturing industries?

SM is very vast and an ongoing requirement for the manufacturing industries which poses a state of confusion in deciding about how and where from to begin for its implementation. This offers a default resistance towards addressing the issues in SM implementation.

Thus, the major objectives of the study are –

- To propose a new basic framework for the implementation of SM
- To develop a validated SEM model for the adoption and enhancement of sustainability in manufacturing.

II METHODOLOGY

One of the major hurdles for the manufacturing firms in implementing SM is a question - how can a manufacturer identify tools and the relevant capabilities to become sustainable [22]? In view of this, the methodology adopted in this study is briefed here. A SMEET framework of five domains has been proposed. A questionnaire has been designed based on five-point Likert scale, which is validated from the industry experts and academicians. Data is collected by sending the validated questionnaire via 'Survey-Monkey' platform to the experts from manufacturing industries in India. The surveyed empirical data is checked for consistency and analyzed using SmartPLS 3 software. Thus, the flow chart of methodology adopted during the study is given below in Fig.1.

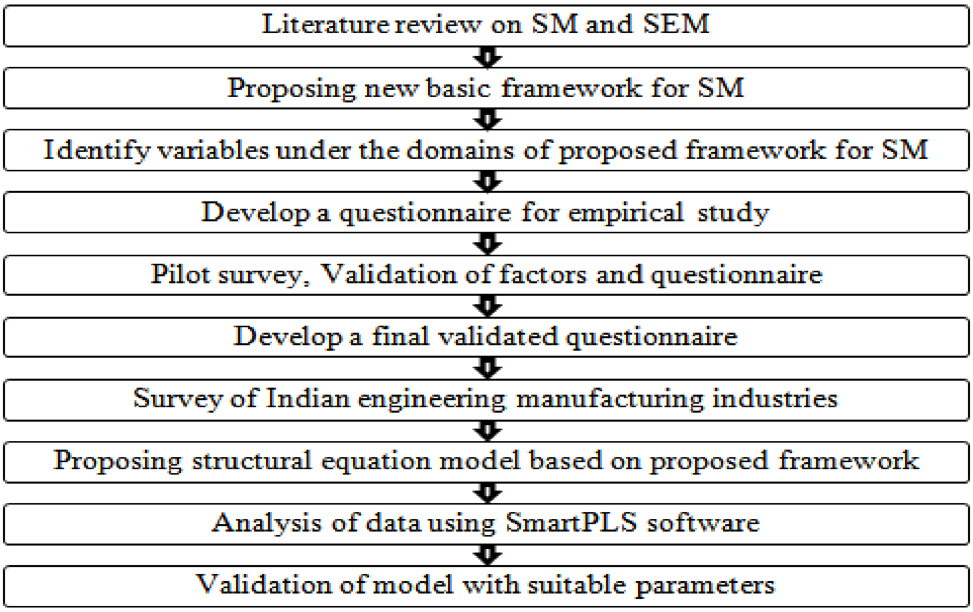

Figure 1: Flowchart for research methodology

III PROPOSED MODEL AND HYPOTHESES

Challenges for manufacturing firms are changing at a faster pace leading to frequent paradigm shifts which is becoming more critical due to mandatory concerns imposed by government over environmental issues [43]. This has been demanding more focus of research in SM towards efficient utilization of overall resources [21]. Traditionally much of the research has been carried out by referring three domains of sustainability i.e. social, economic and environmental [9, 13, 22, 41], as depicted in Fig.2 below.

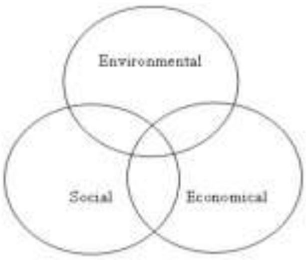

Figure 2: Fundamental structure of sustainable development

Rosen [9] mentioned the need of more comprehensive and integrated approach for the implementation of SM which accounts for considerations beyond three conventional domains of economic, social and environmental aspects. Much less research work has been carried out considering additional domains in such approaches. Kibira [1] proposed an additional domain of 'Manufacturing'; whereas Jovane [32] referred 'Technology' domain in their overall framework. Chow [41] recommended 'Technology' domain for future scope in their study. Shi [35] proposed a separate domain of 'Technical and Information Barriers'. Ghazilla [27] classified variables as drivers and barriers with some of them under 'Technology' domain. Chun [21] conducted a review of literature for 50 years from International Journal of Production Research. They consolidated the potential research opportunities towards integrating academic research with manufacturing industry practices. Sen [39] suggested that the manufacturing enterprises should focus more on the manufacturing based operational practices. In view of these considerations, this paper proposes the framework for the implementation of SM with additional two domains of 'Manufacturing' and 'Technology', as given in Fig.3. Such an attempt is not being made previously to study the aspects in the implementation of SM. The proposed framework has five domains which include '**S**ocial, **M**anufacturing, **E**nvironmental, **E**conomical (Financial), **T**echnology', hence the name '**SMEET**'. A list of variables under five domains of proposed SMEET framework is given in appendix-A.

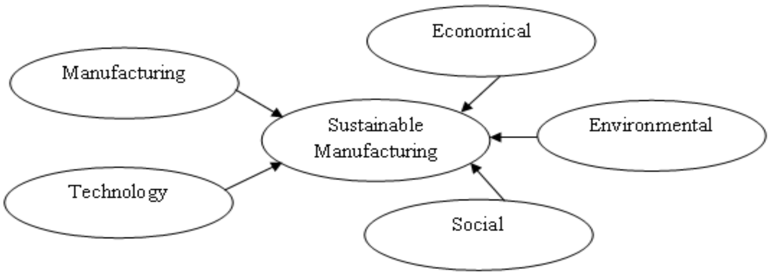

Figure 3: Proposed framework of SM with 5-domains

Following Fig.4 shows flow diagram indcating mapping of SM implementation process with proposed SMEET framework [44]. Capacity planning, aggregate planning and hence profitability of a manufacturing industry are driven by decision making capabilities of the authorities, which fundamentally is confined to manufacturing and technology domains. These decisions need to be taken in correlation with three universal domains of sustainability. Thus, these five domains together decide the net result of manufacturing activities in protecting ecosystem and human life while implementing SM.

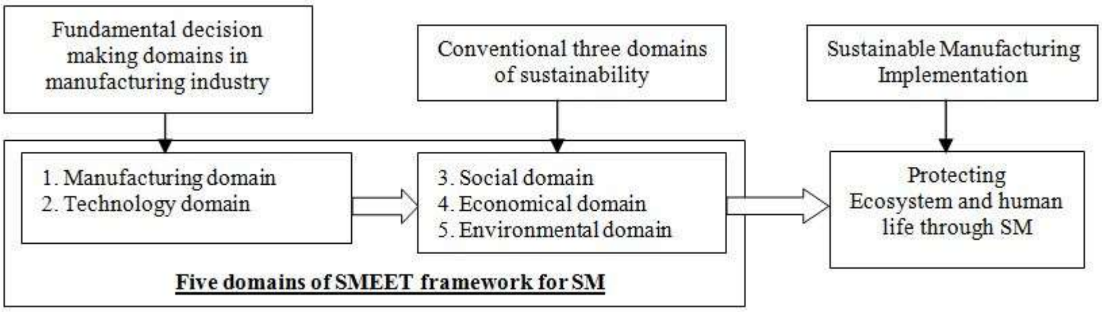

Figure 4: Flow diagram for SM implementation based on SMEET approach

In view of above discussions, following Fig.5 shows the proposed structural equation model.

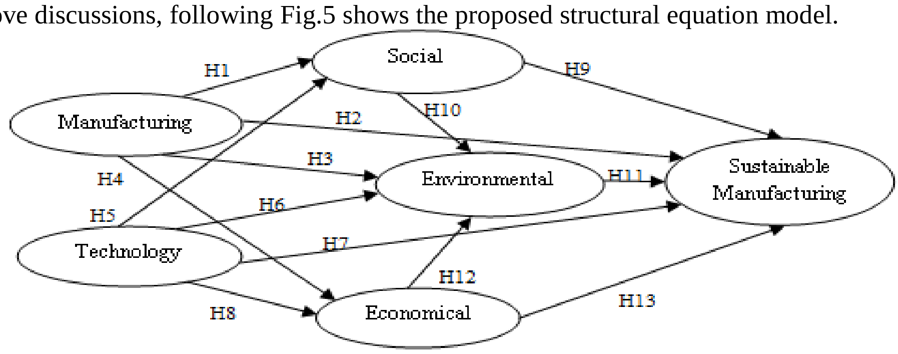

Figure 5: Proposed structural model and hypotheses based on SMEET framework

With a due importance to the domains of 'Manufacturing' and 'Technology', authors proposed 13 hypotheses as listed in following Table-2. The proposed SEM model has been referred in next section for model fit analysis.

Table-2: List of proposed hypotheses

H1	Manufacturing domain and Social domain are correlated
H2	Manufacturing domain and Sustainable Manufacturing domain are correlated
H3	Manufacturing domain and Environmrntal domain are correlated
H4	Manufacturing domain and Economical domain are correlated
H5	Technology domain and Social domain are correlated
H6	Technology domain and Environmrntal domain are correlated
H7	Technology domain and Sustainable Manufacturing domain are correlated
H8	Technology domain and Economical domain are correlated
H9	Social domain and Sustainable Manuafacturing domain are correlated
H10	Social domain and Environmental domain are correlated

H11	Environmental domain and Sustainable Manuafacturing domain are correlated
H12	Economical domain and Environmental domain are correlated
H13	Economical domain and Sustainable Manuafacturing domain are correlated

IV RESULTS AND DISCUSSIONS

Survey Monkey platform was used for conducting the survey of Indian manufacturing industries, which included various fields of automobile, machine tools, pump/motor manufacturing, electrical and other equipments manufacturing, etc. Questionnaire was sent through e-mail to around 999 industries. We received 87 actual responses out of which 15 were incomplete and thus 72 responses were used for data analysis with no missing data. The model fit analysis was carried out using SmartPLS 3.0 software as PLS – SEM approach can handle smaller sample size as well as non-normal data [45].

As a part of model fit analysis, firstly the measurement model evaluations were carried out wherein the factor loadings for some of the items were less than 0.5 which the authors excluded form further analysis. These factor loading values of 0.7 and above are taken to be better while less than 0.4 are recommended to be dropped necessarily [46, 47].

For construct reliability and validity, the values of Composite Reliability (CR), Average Variance Explained (AVE) and Chronbach's alpha are determined and presented in table-3. All these values, except one value of AVE (0.477), indicate satisfactory levels compared with recommended values i.e. Chronbach's Alpha and Composite Reliability values are all greater than 0.7 and AVE greater than 0.5 [46, 47].

Table-3: Construct reliability and validity, and Discriminant validity

	Construct reliability and validity			Discriminant validity					
	Cronbach's Alpha	CR	AVE	ECO	ENV	MFG	SM	SOC	TEC
ECO	0.841	0.886	0.610	**0.781**					
ENV	0.750	0.841	0.573	0.720	**0.757**				
MFG	0.722	0.818	***0.477***	0.547	0.360	**0.691**			
SM	0.935	0.943	0.546	0.401	0.586	0.192	**0.739**		
SOC	0.850	0.893	0.626	0.726	0.603	0.481	0.445	**0.791**	
TEC	0.762	0.839	0.514	0.578	0.680	0.384	0.578	0.569	**0.717**

Discriminant validity is inspected by ways of - Fornell Larcker criterion and Cross-Loadings. Under Fornell Larcker criterion, the diagonal values representing AVE of a latent construct is higher than the constructs' highest square of correlation with any other latent construct, as per the requirement [46, 47]. These values of model evaluations are given in table-8. Cross loading evaluations indicated that the values of indicator loadings within the construct are higher than corresponding indicator values for other constructs, satisfying the validity requirements.

In case of evaluations for structural model, R-square values for all four endogenous constructs ECO, ENV, SM and SOC respectively are 0.458, 0.630, 0.422, and 0.404. The R-square evaluations of 0.75, 0.50, and 0.25 for endogenous constructs are recommended to be substantial, moderate and weak respectively [46]. The model evaluations for all R square parameters are moderate as they are near to 0.5 which can be taken as quite satisfactory and justifying.

Table-4: Discriminant validity – F-square

	ECO	ENV	MFG	SM	SOC	TEC
ECO		0.266		**0.014**		
ENV				0.105		
MFG	0.229	**0.016**		**0.006**	0.135	
SM						
SOC		**0.005**		0.021		
TEC	0.293	0.255		0.092	0.29	

F-square parameter values of 0.02, 0.15 and 0.35 are recommended to have weak, moderate and strong effects [46]. Evaluations of F-square for the proposed model are given in following table-4. It indicates that ECO→SM, MFG→ENV, MFG→SM and SOC→ENV values are having weak effects whereas rest all indicate moderate to strong effects. Bootstrap analysis was carried out for 5000 subsamples and the data analyzed for 13 hypotheses is given in table-5 [46].

Table-5: T-statistics and P-values

	Hypothesis	T-Statistics	P values	Hypothesis
MFG->SOC	H1	3.131	0.002	Supported
MFG->SM	H2	0.521	0.603	Not-Supported
MFG->ENV	H3	1.111	0.267	Not-Supported
MFG->ECO	H4	3.848	0.000	Supported
TEC->SOC	H5	5.554	0.000	Supported
TEC->ENV	H6	3.695	0.000	Supported
TEC->SM	H7	2.961	0.003	Supported
TEC->ECO	H8	5.147	0.000	Supported
SOC->SM	H9	1.311	0.190	Not-Supported
SOC->ENV	H10	0.441	0.659	Not-Supported
ENV->SM	H11	2.765	0.006	Supported
ECO->ENV	H12	3.353	0.001	Supported
ECO->SM	H13	0.802	0.423	Not-Supported

Confidence Level = 1%

The complete model fit analysis given above shows that five hypotheses are not supported by the empirical data. Rest eight hypotheses are well supported as the T values for those hypotheses are more than 1.96 for the confidence level of 1%. The correlation between MFG, SOC and ECO domains with SM as well as MFG and SOC domains with ENV, reflects the need to of further improvements. Thus we can infer that, while implementing SM there is a need to enhance the decision making more towards manufacturing, social and economical domains.

V CONCLUSION

The research activities towards SM implementation need enhancements thereby recognizing eventual tradeoff requirements to be exercised. The major research so far in SM is centered towards three conventional domains of environmental, economical and social aspects. We have proposed a SMEET framework for SM implementation with a focus on manufacturing and technology domains, which is the novel contribution of this paper. The review of literature showed a large scope for research towards SM implementation as well as for applying SEM approach.

Considering the discussions from previous section and results from table-5 we conclude that the manufacturing as well as social domain activities do not indicate satisfactory correlation with the domains of ‘Environmental’ and ‘Sustainable Manufacturing’. Economical domain also exhibit poor performance of its association with the domain of ‘Sustainable Manufacturing’. We infer from this that Indian engineering manufacturing industries need to enhance their strategic decisions towards various domain related aspects so as to improve its correlation with the ‘Environmental’ and ‘Sustainable Manufacturing’ domains. With this we foresee an ample scope for the enhancement of SM implementation in Indian engineering manufacturing industries.

This research may further be extended in studying the mediation and moderation analysis of various constructs and variables. The future scope is recommended towards applying various MCDM/MODM techniques to SM implementation with proposed SMEET framework as well as extending SEM applications to a set of different critical variables under various domains of SMEET framework. This work is expected to provide a systematic approach for SM implementations in manufacturing organizations across different geographical regions.

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APPENDIX-A

List of variables under different domains in proposed SMEET framework

Variable	**References**
Social Domain	
1. Customer Satisfaction	Rosen [9], Amrina [13], Garetti [23], Singh [28], Jovane [32], Severo [42], Shao [48], Joung [49]
2. Employee Satisfaction	Amrina [13], Ghazilla [27], Severo [42], Joung [49], Oliveira [50]

3. Health, Safety, Security of employees	Rosen [9], Amrina [13], Feng [15], Jovane [32], Shankar [37], Shao [48], Joung [49], Shi [51]
4. Work culture	Diana [8], Rosen [9], Ghazilla [27], Oliveira [50]
5. Corporate Social Responsibility (CSR)	Rosen [9], Amrina [13], Ghazilla [27], Singh [28], Joung [49], Shi [51], Habidin [52]
Manufacturing Domain	
1. Inventory Quantity	Kibira [1], Amrina [13], Severo [42], Habidin [52]
2. Labour Turnover	Kibira [1], Amrina [13], Singh [28]
3. Material Waste	Kibira [1], Amrina [13], Feng [15], Garetti [23], Singh [28], Haapala [40], Severo [42], Shao [48], Joung [49], Seidel [53]
4. Internal Material Handling	Abdulrahman [54]
5. Non Value-Adding Time (NVAT) elements	Amrina [13], Thanki [20]
Environmental Domain	
1. Pollutants	Kibira [1], Rosen [9], Amrina [13], Feng [15], Singh [28], Haapala [40], Severo [42], Shao [48], Joung [49], Shi [51], Habidin [52]
2. Energy Saving / Generation	Kibira [1], Rosen [9], Amrina [13], Feng [15], Vinodh [22], Garetti [23], Singh [28], Jovane [32], Trianni [33], Shankar [37], Haapala [40], Severo [42], Shao [48], Habidin [52]
3. Environmental Regulations	Kibira [1], Bhanot [10], Bhanot [12], Ghazilla [27], Mittal [34], Oliveira [50]
4. Recycling, Re-manufacture, Reuse	Rosen [9], Ghazilla [27], Jovane [32], Shankar [37], Shao [48], Shi [51], Habidin [52], Abdulrahman [54], Hu [55]
5. Suppliers	Kibira [1], Amrina [13], Ghazilla [27], Severo [42], Shi [51], Habidin [52]
Economical Domain	
1. Profitability	Kibira [1], Bhanot [12], Jovane [32], Seidel [53]
2. Financial Constraints	Kibira [1], Bhanot [10], Bhanot [12], Vinodh [22], Ghazilla [27], Jovane [32], Mittal [34], Shi [35]Oliveira [50], Abdulrahman [54]
3. Government Incentives	Rosen [9], Ghazilla [27], Shi [35]
4. Manufacturing costs	Bhanot [10], Amrina [13], Singh [28], Jovane [32], Shankar [37], Haapala [40], Severo [42], Joung [49]
5. Quality Costs	Dawal [6], Rosen [9], Amrina [13], Singh [28], Shankar [37], Severo [42]
Technology Domain	
1. Technology awareness	Bhanot [10], Bhanot [12], Garetti [23], Ghazilla [27], Mittal [34], Shi [35], Shankar [37], Joung [49], Oliveira [50], Abdulrahman [54]
2. Skill/ Expertise	Garetti [23], Ghazilla [27], Mittal [34], Shi [35], Oliveira [50], Abdulrahman [54]
3.Training and Education	Diana [8], Bhanot [10], Bhanot [12], Amrina [13], Garetti [23], Ghazilla [27], Singh [28], Shi [35], Shankar [37], Severo [42], Shao [48], Oliveira [50]
4. Research and Development	Amrina [13], Dewangan [26], Ghazilla [27], Jovane [32], Joung [49]
5. Flexibility	Dawal [6], Amrina [13], Garetti [23], Ghazilla [27], Singh [28], Shankar [37]
6. Information and Communication Technology (ICT)	Diana [8], Garetti [23], Dewangan [26], Jovane [32], Trianni [33], Shi [35]

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