Int J Syst Assur Eng Manag (December 2016) 7(4):400–407
DOI 10.1007/s13198-016-0461-z

ORIGINAL ARTICLE

# Two-way assessment of barriers to Lean–Green Manufacturing System: insights from India

**Varinder Kumar Mittal[1] · Rahul Sindhwani[1] · P. K. Kapur[2]**

Received: 23 March 2016 / Published online: 23 April 2016


**Abstract** Manufacturing systems across the globe are under pressure to improve the competitiveness and environmental performance. However, neither of lean manufacturing (LM) nor green manufacturing (GM) concepts distinctly provides a comprehensive workable solution to the challenges of the competitiveness and environmental performance. There is a need to make a bridge between LM and GM. So, a hybrid system of Lean–Green Manufacturing System (LGMS) is proposed which can handle the challenges of the manufacturing systems completely. However, adoption of such manufacturing systems in the existing industrial framework poses many issues which hinder the implementation of such system, although it leads to holistic improvement of manufacturing system performance. These issues are termed as 'barriers'. In this research, a comprehensive and thorough study of the LM, GM and LGMS has been done to identify the barriers. These barriers are suitably analyzed to bring out some insights which can help them mitigate. This will enable the voluntary transition towards LGMS more realistically. Barriers will be analyzed and validated with the help of two-way assessment approach. This research will contribute to the scientific literature by providing a validated list of barriers and few high impact barriers which will provide the ground for policy makers in industry and government to frame policies which are more implementable.

**Keywords** Lean–Green Manufacturing Systems · Barriers · Analytical hierarchy process (AHP) · Two-way assessment

## 1 Introduction

Manufacturing systems across the globe are under pressure to improve the competitiveness and environmental performance. The competitiveness of the manufacturing function is well addressed by lean concept which works on the principle of reduction of various wastes where as the environmental performance which aims at minimizing the effect of manufacturing system on environment is addressed by the green concept.

During the end of the twentieth century and the beginning of twenty-first century two types of manufacturing systems gained popularity which emphasized waste minimization. 'Lean' manufacturing systems reduce waste in terms of non-value added activities, and 'Green' manufacturing systems reduce waste in terms of adverse environmental impact (Sawhney et al. 2007). However, the green manufacturing (GM) system implementation pace is slow in comparison to the rapid global growth of the manufacturing industry, and thus over time the industry is becoming less 'sustainable. Lean manufacturing (LM) is gaining popularity worldwide as a premier alternative to the outdated mass production model, for producing quality product, at the less cost and lead time. So, if GM can be integrated with LM, such that lean serves as a catalyst to GM implementation, then economically and

✉ Varinder Kumar Mittal
varindermittal@gmail.com

[1] Amity School of Engineering and Technology, Amity University, Uttar Pradesh, Sector 125, Noida, Uttar Pradesh 201313, India

[2] Amity Centre for Interdisciplinary Research, Amity University, Uttar Pradesh, Sector 125, Noida, Uttar Pradesh 201313, India

environmentally sustainable manufacturing could be realized (Kainuma and Tawara 2006). The literature reveals that lean companies show significant environmental improvements by being more resource and energy efficient. The literature also indicates that how both manufacturing systems have commonalities of best practices to reduce their respective wastes (Yang et al. 2011). In spite of these facts, the reality remains that these two systems tend to operate independently, organized by different personnel, even within the same manufacturing system.

However, neither of these two concepts distinctly provides a comprehensive workable solution to the challenges of the competitiveness and environmental performance. There is a need to make a bridge between LM and GM systems. So, a hybrid system of Lean–Green Manufacturing System (LGMS) is proposed which can handle the challenges of the manufacturing systems completely. However, adoption of some new system in existing industrial framework poses some issues which hinder the implementation of the new system, although it leads to holistic improvement of manufacturing system performance. These issues are termed as ‘barriers’ in this research.

In this research, a comprehensive and thorough study of the LM system and GM system is done. Additionally, the literature on the lean green manufacturing system has been used to identify the barriers. Before putting these barriers for analysis, brain storming with many stakeholders like academician, researchers, industry experts, etc. is done to ensure that all barriers prevailing in Indian setup are listed and nothing is left.

These barriers are suitably analyzed to bring out some insights which can help them mitigate. This will enable the voluntary transition towards LGMS more realistically. Barriers will be analyzed with the help of two-way assessment approach to validate the barriers to LGMS. Firstly the pair-wise comparison of different barriers by experts is utilized using analytical hierarchy process (AHP) technique to obtain weights. Secondly, the opinion of stakeholders is used to substantiate the assessment by different group of people. Finally this will help in finding out the impact of barriers during the implementation of LGMS. This research will contribute to the scientific literature by providing a validated list of barriers which will provide a ground for policy makers in industry and government of India to frame policies which are more implementable voluntarily. Rest of the paper is structured as follows: next section focuses on literature review followed by methodology adopted for the study in sect. 3. Section 4 presents results and discussion. Finally, sect. 5 provides conclusion of the study followed by acknowledgements and references.

## 2 Literature review

A lot of research has been done in the past on LM (Fullerton et al. 2014; Jabbour et al. 2013; Rahman et al. 2013) and GM (Mittal and Sangwan 2014a, 2014b; Sangwan and Mittal 2015; Singh et al. 2012; Mittal and Sangwan 2015) systems. Lean focuses on reducing the wastes in manufacturing, thereby reducing costs while GM focuses on reducing environmental impact of the manufacturing, thereby reducing environmental degradation. Lean manufacturing reduces manufacturing costs which enable the manufacturers to earn more profits or competitiveness, but there is less for the consumers to gain directly (Kainuma and Tawara 2006). Green manufacturing improves the environmental performance which enables the minimum impact on environment, but there is less for the consumers and manufacturers to gain directly (Elsayed et al. 2013). So, the LGMS provides the win–win situation for the world wherein all are benefited while the products are manufactured and consumer needs are satisfied with minimum environmental impact.

Manufacturers are quickly changing their manufacturing systems from traditional manufacturing to LM systems. This LM system allows effective production of small quantities of products at high levels of quality. Even high volume manufacturers companies find that lean systems are justified alone for the resource efficiency and quality benefits (Bergmiller 2006). Early articles and books on LM focused on lean waste reducing techniques and gave little attention to the management system aspects of this system. For the early observers of lean companies like Toyota in Japan, it was obvious to see the waste reducing techniques in practice out on the factory floor (i.e. KANBAN systems, work cells). However it became clear after companies tried for decades to implement the waste reducing techniques, which these solutions were not sustainable, and the companies implementing them were not achieving the same lean results as they saw in Japan. Womack and Jones (1996) describes lean production as a system that uses less, in terms of all inputs, to create outputs similar to those of traditional mass production systems, while offering increased choices for the final consumer.

Wang et al. (2008) analyzed 13 barriers to energy saving for China through the literature review and suggestions from the experts of industry and academia. Studer et al. (2006) also examined barriers to involve Hong Kong business with planned environmental initiation. Zhang et al. (2009) also find out ten barriers related to environmental management initiative in China with the help of questionnaire survey. Shi et al. (2008) find out the barrier to cleaner production (CP) by SMEs in China and analyzed the barriers with analytic hierarchy process (AHP) and

**Table 1** Barriers to LGMS

| Sr. | Barrier name | Barrier description |
|---|---|---|
| $B_{11}$ | Misconceptions about LGMS | There are many misconceptions among the industry that these new manufacturing strategies would not yield anything but consume investments |
| $B_{12}$ | Reluctance to production disruptions | Firms do not want to disrupt their routine manufacturing for the change to better systems as they fear the loss of production may cause losing customers |
| $B_{13}$ | Low consumer awareness | Merely price sensitive consumers do not value a product which consumed least resources for manufacturing with minimum environmental impact |
| $B_{21}$ | Scarce resources | Limited technical, human and financial resources of the firms to adopt and maintain new manufacturing strategies |
| $B_{22}$ | Inadequate regulatory framework | The insufficient regulatory framework to direct the firms for manufacturing efficiencies and environmental performance |
| $B_{23}$ | Lack of technical information | Lack of technical know how to handle the new technology |
| $B_{31}$ | Resistance to change | The resistance of the firms to mend the ways of doing works even if they are beneficial and/or cost effective |
| $B_{32}$ | Lack of management commitment | The lack of voluntary obligation of the management to support the change whole heartedly |
| $B_{33}$ | Inadequate employee involvement | The involvement of all levels of the employees is missing to adopt new strategies |
| $B_{34}$ | Inadequate organizational structure | Inefficient organizational structure hinders the flow of information to various levels of hierarchy |

Cooray (1999) also worked on CP barriers in Sri Lankan SME's through a survey of hospitals, food and beverages. Zhang (2000), Yuksel (2008) and Siaminwe et al. (2005) also tried to find out the barriers for implementation of CP program in China, Turkey and Zambian industry respectively. Montalvo (2008) presents a selective survey of papers from 1997 to 2007 for representing the barriers affecting adoption, diffusion, and exploitation of cleaner technologies. Singh et al. (2012) presented 12 barriers affecting GM practices in Indian industry.

A small number of scholarly studies have investigated the relationship between lean and green manufacturing systems (Bergmiller 2006). These studies show a positive relationship between lean and green. Rothenberg et al. (2001) study shows that lean companies have better environmental performance and embrace environmental waste minimization more so than non-lean companies. Florida (1996) study identified some common best practices between lean and green management systems (e.g. management commitment, teams, new process technology, innovative product design, and supply chain management). Florida (1996) indicated that these techniques are associated with both lean and green manufacturing systems. Advanced manufacturing facilities, such as those organized under the principles of lean production, draw on the same underlying principles—a dedication to productivity improvement, quality, cost reduction, and continuous improvement, and technology innovation—that underlie environmental innovation. King and Lenox (2001) study finds that companies with low inventories of hazardous materials and who are ISO9001 certified have lower toxic emissions than companies with higher inventories and is not ISO9001 certified. Each of these studies shows correlation between some elements of a GM system and some aspects of a LM system. Bergmiller (2006) study showed how lean has direct green benefits as a bi product of efficiency gains.

The thorough exploration of the literature, discussion with researchers working in this field, and industry executives knowledgeable about the subject has led to identification of ten barriers which hinder the adoption of such new systems which can yield immense benefits to the industry in all aspects as shown in Table 1. In order to apply AHP, three criteria are decided in consultation with experts as shown in Table 2.

## 3 Methodology

Analytical hierarchy process has been widely used in the literature to analyze the factors influencing manufacturing systems. It involves pare-wise comparison of the factors by expert's views. On the similar lines, a two-way assessment is used in the current research to analyze the barriers to LGMS. The stepwise methodology adopted for the research is listed below:

1. Identification of LGMS barriers
   Identification of barriers to LGMS through a review of literature and discussion with experts from industry and academia are shown in Table 1. Also, the three criteria chosen to establish the hierarchical structure of barriers are selected as shown in Table 2.

**Table 2** Criteria for LGMS barriers

| Sr. | Criteria name | Criteria description |
|---|---|---|
| $C_1$ | Economic perspective | This criteria involves financial aspect involving cost, capital, etc |
| $C_2$ | Technical perspective | This criteria involves technical aspects involving technology, maintenance, installation, etc |
| $C_3$ | Organizational perspective | This criterion involves organizational aspects involving issues related to within the organization and management |

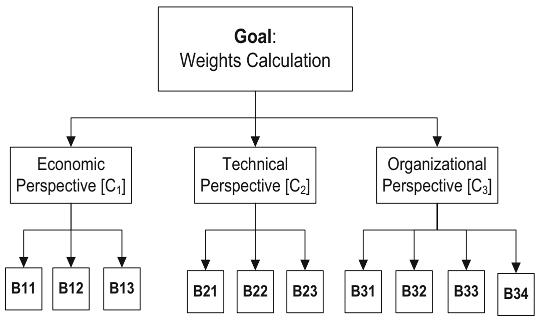


**Fig. 1** Hierarchical structure of LGMS barriers

2. Establishment of hierarchy
   Establishment of hierarchy of various barriers using three criteria in consultation with experts as discussed above (Fig. 1).
3. Application of AHP
   Application of AHP to get the overall weights of each barrier using pair-wise comparison through inputs from industrial managers involved in operations management and decision making.

Before calculating the weights, the consistency of the pair-wise comparison of criteria and barriers should be checked. The consistency of the pair-wise comparison can be checked as follows:

- Calculate the largest eigen value ($\lambda_{max}$).
- Check the Consistency Ratio (CR).

The consistency of the comparison matrix can be determined by the CR, which is defined as:

$$CR = \frac{CI}{RI} = \frac{\lambda_{\max} - n}{RI(n-1)}$$

where CI is the consistency index, RI is the random index, 'n' is the matrix size.

As a rule, only if CR < 0.10, the consistency of the matrix is considered as acceptable, otherwise the pair-wise comparisons should be revised. The RI values for sizes 1, 2, 3, 4, 5, 6, 7, 8, 9 are taken as 0.00, 0.00, 0.58, 0.90, 1.12, 1.24, 1.32, 1.41, 1.45 respectively.

The raw inputs using Likert's scale (1–5), the normalized inputs and the weights of the criteria and barriers to LGMS are presented in Tables 3, 4, 5 and 6. The $\lambda_{max}$, C.I. and C.R. of each case is provided at the foot of each table.

**Table 3** Inputs, normalized inputs, and criteria weights

| | Inputs | | | Normalized inputs | | | Weight |
|---|---|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ | $C_1$ | $C_2$ | $C_3$ | |
| $C_1$ | 1 | 3 | 1 | 0.429 | 0.375 | 0.444 | 1.248 |
| $C_2$ | 1/3 | 1 | ¼ | 0.143 | 0.125 | 0.111 | 0.379 |
| $C_3$ | 1 | 4 | 1 | 0.429 | 0.5 | 0.444 | 1.373 |
| Sum | 2.33 | 8 | 2.25 | | | | |

$\lambda_{max}$ = 3.0092, C.I. = 0.00460136, C.R. = 0.0079

**Table 4** Inputs, normalized inputs, and barrier weights

| | Inputs | | | Normalized inputs | | | Weights |
|---|---|---|---|---|---|---|---|
| | $B_{11}$ | $B_{12}$ | $B_{13}$ | $B_{11}$ | $B_{12}$ | $B_{13}$ | |
| $B_{11}$ | 1 | ½ | 4 | 0.307 | 0.273 | 0.5 | 1.08 |
| $B_{12}$ | 2 | 1 | 3 | 0.615 | 0.546 | 0.375 | 1.536 |
| $B_{13}$ | ¼ | 1/3 | 1 | 0.077 | 0.182 | 0.125 | 0.384 |
| Sum | 3.25 | 1.83 | 8 | | | | |

$\lambda_{max}$ = 3.10785, C.I. = 0.0539237, C.R. = 0.0929

**Table 5** Inputs, normalized inputs, and barrier weights

| | Inputs | | | Normalized inputs | | | Weights |
|---|---|---|---|---|---|---|---|
| | $B_{21}$ | $B_{22}$ | $B_{23}$ | $B_{21}$ | $B_{22}$ | $B_{23}$ | |
| $B_{21}$ | 1 | 1/3 | ½ | 0.166 | 0.182 | 0.143 | 0.491 |
| $B_{22}$ | 3 | 1 | 2 | 0.5 | 0.546 | 0.571 | 1.617 |
| $B_{23}$ | 2 | ½ | 1 | 0.333 | 0.273 | 0.286 | 0.892 |
| Sum | 6 | 1.83 | 3.5 | | | | |

$\lambda_{max}$ = 3.0092, C.I. = 0.00460136, C.R. = 0.0079

Table 7 presents the weights of all the criteria and barriers to LGMS which is calculated in Tables 3, 4, 5 and 6 for calculation of global weights.

4. Two-way assessment
   The two-way assessment of the impact of barriers through inputs primary from middle management like industry managers, operations managers, etc. and after that the global weights are calculated with the help of AHP technique which is calculated in previous step and second view is taken from stakeholder i.e. top management like general manager, chief executive officer,

**Table 6** Inputs, normalized inputs, and barrier weights

| | Inputs | | | | Normalized inputs | | | | Weights |
|---|---|---|---|---|---|---|---|---|---|
| | $B_{31}$ | $B_{32}$ | $B_{33}$ | $B_{43}$ | $B_{31}$ | $B_{32}$ | $B_{33}$ | $B_{43}$ | |
| $B_{31}$ | 1 | ½ | 4 | 1/3 | 0.16 | 0.214 | 0.363 | 0.091 | 0.828 |
| $B_{32}$ | 2 | 1 | 3 | 2 | 0.32 | 0.429 | 0.272 | 0.546 | 1.567 |
| $B_{33}$ | ¼ | 1/3 | 1 | 1/3 | 0.04 | 0.143 | 0.091 | 0.091 | 0.365 |
| $B_{34}$ | 3 | ½ | 3 | 1 | 0.48 | 0.214 | 0.272 | 0.273 | 1.239 |
| Sum | 6.25 | 2.33 | 11 | 3.66 | | | | | |
| $\lambda_{max} = 4.29377$, C.I. = 0.097924, C.R. = 0.1088 | | | | | | | | | |

**Table 7** Criteria and barrier weights

| | | |
|---|---|---|
| $C_1 = 1.248$ | $C_2 = 0.379$ | $C_3 = 1.373$ |
| $B_{11} = 1.08$ | $B_{21} = 0.491$ | $B_{31} = 0.828$ |
| $B_{12} = 1.536$ | $B_{22} = 1.617$ | $B_{32} = 1.567$ |
| $B_{13} = 0.384$ | $B_{23} = 0.892$ | $B_{33} = 0.365$ |
| | | $B_{34} = 1.239$ |

managing director, etc. as shown in Table 8. Ideal, worst and average cases of two-way assessment of barriers to LGMS are described in Tables 9, 10 and 11. Finally, this will help in finding out the impact of barriers in two-way during the implementation of LGMS.

5. Establishment of the impact of barriers
   Finally using the two-way assessment of actual, ideal, average and worst cases the impact of barriers to LGMS is assessed.

## 4 Results and discussion

The impact of barriers to LGMS implementation is presented in Table 8. At the same time, the impacts in the ideal, worst and average case are also presented in Tables 9, 10 and 11. This will help to analyze the impact relative to its maximum possible impact, least possible impact, and average impact. Referring to Table 8, reluctance to production disruption ($B_{12}$), lack of management commitment ($B_{32}$), misconception about LGMS ($B_{11}$), and resistance to change ($B_{31}$) impacted 29.27, 12.32, 11.57 and 10.13 % respectively. Two-third impact of barriers to LGMS implementation is because of these four barriers alone. Rest one-third impact is contributed by remaining six barriers altogether. As per above study, scarce resources, lack of technical information and low consumer awareness impact 2.07, 2.80 and 6.10 % respectively. All these three combined impact less than 10 %, so there is less need to focus more on these three barriers. On the other hand, remaining three barriers viz. inadequate regular framework, inadequate employ involvement and inadequate organizational structure impact 8.97, 7.02 and 9.74 % respectively, so these barriers are also known as medium impact barriers. Finally this study shows that firstly there is a need to focus on four high impact barriers followed by the three medium impact barriers for easy, effective, efficient and timely implementation of LGMS in Indian manufacturing industry.

**Table 8** Two-way assessment of LGMS barriers (actual case)

| Barrier | Normalized global weights | Levels[a] | | | | | Expected level weights | CTI[b] |
|---|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | | |
| $B_{11}$ | 12.99 | 0 | 0.3 | 0.3 | 0.2 | 0.2 | 2.7 | 35.07 (11.57 %) |
| $B_{12}$ | 18.48 | 0.8 | 0.2 | 0 | 0 | 0 | 4.8 | 88.69 (29.27 %) |
| $B_{13}$ | 4.62 | 0 | 0.8 | 0.1 | 0.1 | 0 | 4.0 | 18.47 (6.10 %) |
| $B_{21}$ | 1.79 | 0 | 0.6 | 0.3 | 0.1 | 0 | 3.5 | 6.27 (2.07 %) |
| $B_{22}$ | 5.91 | 0.7 | 0.2 | 0.1 | 0 | 0 | 4.6 | 27.19 (8.97 %) |
| $B_{23}$ | 3.26 | 0 | 0.3 | 0.2 | 0.3 | 0.2 | 2.6 | 8.47 (2.80 %) |
| $B_{31}$ | 10.97 | 0 | 0.4 | 0.2 | 0.2 | 0.2 | 2.8 | 30.70 (10.13 %) |
| $B_{32}$ | 20.74 | 0 | 0 | 0 | 0.8 | 0.2 | 1.8 | 37.34 (12.32 %) |
| $B_{33}$ | 4.83 | 0.6 | 0.2 | 0.2 | 0 | 0 | 4.4 | 21.25 (7.02 %) |
| $B_{34}$ | 16.40 | 0 | 0 | 0.4 | 0.2 | 0.4 | 1.8 | 29.52 (9.74 %) |
| Overall utility measure | | | | | | | | 303.02 (100 %) |

[a] 5: Very important; 4: important; 3: moderately important; 2: less important; 1: least important

[b] Contribution to the total Impact

**Table 9** Two-way assessment of LGMS barriers (ideal case)

| Barrier | Normalized global weights | Levels[a] | | | | | Expected level weights | CTI[b] |
|---|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | | |
| $B_{11}$ | 12.99 | 1 | 0 | 0 | 0 | 0 | 5 | 64.95 (12.99 %) |
| $B_{12}$ | 18.48 | 1 | 0 | 0 | 0 | 0 | 5 | 92.4 (18.48 %) |
| $B_{13}$ | 4.62 | 1 | 0 | 0 | 0 | 0 | 5 | 23.1 (4.62 %) |
| $B_{21}$ | 1.79 | 1 | 0 | 0 | 0 | 0 | 5 | 8.95 (1.79 %) |
| $B_{22}$ | 5.91 | 1 | 0 | 0 | 0 | 0 | 5 | 29.55 (5.91 %) |
| $B_{23}$ | 3.26 | 1 | 0 | 0 | 0 | 0 | 5 | 16.3 (3.26 %) |
| $B_{31}$ | 10.97 | 1 | 0 | 0 | 0 | 0 | 5 | 54.85 (10.97 %) |
| $B_{32}$ | 20.74 | 1 | 0 | 0 | 0 | 0 | 5 | 103.7 (20.74 %) |
| $B_{33}$ | 4.83 | 1 | 0 | 0 | 0 | 0 | 5 | 24.15 (4.83 %) |
| $B_{34}$ | 16.4 | 1 | 0 | 0 | 0 | 0 | 5 | 82 (16.40 %) |
| Overall Utility Measure | | | | | | | | 499.95 (100 %) |

[a] 5: Very important; 4: important; 3: moderately important; 2: less important; 1: least important

[b] Contribution to the total impact

**Table 10** Two-way assessment of LGMS barriers (worst case)

| Barrier | Global weights | Levels[a] | | | | | Expected level weights | CTI[b] |
|---|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | | |
| $B_{11}$ | 12.99 | 0 | 0 | 0 | 0 | 1 | 1 | 12.99 (12.99 %) |
| $B_{12}$ | 18.48 | 0 | 0 | 0 | 0 | 1 | 1 | 18.48 (18.48 %) |
| $B_{13}$ | 4.62 | 0 | 0 | 0 | 0 | 1 | 1 | 4.62 (4.62 %) |
| $B_{21}$ | 1.79 | 0 | 0 | 0 | 0 | 1 | 1 | 1.79 (1.79 %) |
| $B_{22}$ | 5.91 | 0 | 0 | 0 | 0 | 1 | 1 | 5.91 (5.91 %) |
| $B_{23}$ | 3.26 | 0 | 0 | 0 | 0 | 1 | 1 | 3.26 (3.26 %) |
| $B_{31}$ | 10.97 | 0 | 0 | 0 | 0 | 1 | 1 | 10.97 (10.97 %) |
| $B_{32}$ | 20.74 | 0 | 0 | 0 | 0 | 1 | 1 | 20.74 (20.74 %) |
| $B_{33}$ | 4.83 | 0 | 0 | 0 | 0 | 1 | 1 | 4.83 (4.83 %) |
| $B_{34}$ | 16.4 | 0 | 0 | 0 | 0 | 1 | 1 | 16.4 (16.4 %) |
| Overall utility measure | | | | | | | | 99.99 (100 %) |

[a] 5: Very important; 4: important; 3: moderately important; 2: less important; 1: least important

[b] Contribution to the total impact

## 5 Conclusion

This paper presented three criteria and ten barriers to LGMS identified through the review of existing literature on LM, GM, and lean–green manufacturing combined. The identified barriers are also reviewed in consultation with experts from academia and industry. As the AHP methodology involves few experts, so the impact of the barriers in terms of global weights is primarily accessed with inputs from industrial managers by using AHP and then cross-assessed using impact assessment theory. This methodology uses inputs from two different stakeholders differently and named it as two-way assessment of barriers to LGMS.

This analysis of barriers will help policy makers in government and industrial sectors to enable them to frame policies and directives to progress the industry in harmony with competitiveness and environment. The implementation of newer, better, and more effective systems is not an easy task particularly in developing countries like India which has limited resources and different social behavior. So, the analysis of the factors influencing the implementation of newer manufacturing systems will yield useful insights for policy makers.

A careful look at the barriers to LGMS reveals that these barriers are not exclusively independent and have some kind of inter-relationship among them. This inter-relationship among these barriers need to be investigated using

**Table 11** Two-way assessment of LGMS barriers (average case)

| Barrier | Global weights | Levels[a] | | | | | Expected level weights | CTI[b] |
|---|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | | |
| $B_{11}$ | 12.99 | 0 | 0 | 1 | 0 | 0 | 3 | 38.97 (12.99 %) |
| $B_{12}$ | 18.48 | 0 | 0 | 1 | 0 | 0 | 3 | 55.44 (18.48 %) |
| $B_{13}$ | 4.62 | 0 | 0 | 1 | 0 | 0 | 3 | 13.86 (4.62 %) |
| $B_{21}$ | 1.79 | 0 | 0 | 1 | 0 | 0 | 3 | 5.37 (1.79 %) |
| $B_{22}$ | 5.91 | 0 | 0 | 1 | 0 | 0 | 3 | 17.73 (5.91 %) |
| $B_{23}$ | 3.26 | 0 | 0 | 1 | 0 | 0 | 3 | 9.78 (3.26 %) |
| $B_{31}$ | 10.97 | 0 | 0 | 1 | 0 | 0 | 3 | 32.91 (10.97 %) |
| $B_{32}$ | 20.74 | 0 | 0 | 1 | 0 | 0 | 3 | 62.22 (20.74 %) |
| $B_{33}$ | 4.83 | 0 | 0 | 1 | 0 | 0 | 3 | 14.49 (4.83 %) |
| $B_{34}$ | 16.4 | 0 | 0 | 1 | 0 | 0 | 3 | 49.2 (16.4 %) |
| Overall utility measure | | | | | | | | 299.97 (100 %) |

[a] 5: Very important; 4: important; 3: moderately important; 2: less important; 1: least important

[b] Contribution to the total Impact

Interpretive Structural Modelling (ISM), also possibly using a two-way assessment approach to further compare and confirm the finding obtained in this paper.

As this is relatively new research area and very limited research is done in the field of LGMS, so it is required to investigate same and/or similar factors using inputs from different stakeholders and using analysis techniques for better understanding of the implementation issues.

**Acknowledgments** Authors express their sincere gratitude to Dr. A. K. Chauhan, The Founder President, Amity University for his keen interest in promoting and supporting research at Amity University Uttar Pradesh, Noida. Author's feels obliged to acknowledge the valuable inputs by the experts, which was indispensable for writing of this paper.

## References

Bergmiller GG (2006) Lean manufacturers transcendence to green manufacturing: correlating the diffusion of lean and green manufacturing systems. Graduate Theses and Dissertations (Thesis No. 2457), University of South Florida, USA. http://scholarcommons.usf.edu/etd/2457. Accessed 21 Dec 2015

Cooray N (1999) Cleaner production assessment in small and medium industries of Sri Lanka, global competitiveness through cleaner production. In: Proceedings of the second Asia Pacific Cleaner Production Roundtable, Brisbane, 21–23 April, pp 108–114

Elsayed ND, Jondral A, Greinacher S, Dornfeld D, Lanza G (2013) Assessment of lean and green strategies by simulation of manufacturing systems in discrete production environments. CIRP Ann-Manuf Technol 62(1):475–478

Florida R (1996) Lean and green: the move to environmentally conscious manufacturing. California Management Review, 39(1): 80-105. doi:10.2307/41165877

Fullerton RR, Kennedy FA, Widener SK (2014) Lean manufacturing and firm performance: the incremental contribution of lean management accounting practices. J Operations Manag 32(7–8): 414–428

Jabbour CJC, Jabbour ABLdeS, Govindan K, Teixeira AA, Freitas WRdeS (2013) Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing. J Clean Prod 47:29–140

Kainuma Y, Tawara N (2006) A multiple attribute utility theory approach to lean and green supply chain management. Int J Prod Econ 101(1):99–108

King A, Lenox M (2001) Lean and green? An empirical examination of the relationship between lean production and environmental performance. Prod Oper Manag 10(3):244–257

Montalvo C (2008) General wisdom concerning the factors affecting the adoption of cleaner technologies—a survey 1990–2007. J Clean Prod 16(1):7–13

Mittal VK, Sangwan KS (2014a) Prioritizing barriers to green manufacturing: environmental, social and economic perspectives. Procedia CIRP 17:559-564

Mittal VK, Sangwan KS (2014b) Prioritizing drivers for green manufacturing: environmental, social and economic perspectives. Procedia CIRP 15:135–140

Mittal VK, Sangwan KS (2015) Ranking of drivers for green manufacturing implementation using fuzzy technique for order of preference by similarity to ideal solution method. J Multi-Crit Decis Anal 22:119–130

Rahman NAA, Sharif SM, Esa MM (2013) Lean manufacturing case study with Kanban system implementation. Procedia Econ Finance 7:174–180

Rothenberg S, Pil FK, Maxwell J (2001) Lean, green, and the quest for superior environmental performance. Prod Oper Manag 10(3):228–243

Sangwan KS, Mittal VK (2015) A bibliometric analysis of green manufacturing and similar frameworks. Manag Environ Qual Int J 26(4):566–587

Sawhney R, Teparakul P, Bagchi A, Li X (2007) En-Lean: a framework to align lean and green manufacturing in the metal cutting supply chain. Int J Enterp Netw Manag 1(3):238–260

Shi H, Peng SZ, Liu Y, Zhong P (2008) Barriers to the implementation of cleaner production in Chinese SMEs—government, industry and expert stakeholders' perspectives. J Clean Prod 16(7):842–852

Siaminwe L, Chinsembu KC, Syakalima M (2005) Policy and operational constraints for the implementation of cleaner production in Zambia. J Clean Prod 13(10–11):1037–1047

Singh A, Singh B, Dhingra AK (2012) Drivers and barriers of green manufacturing practices: a survey of Indian industries. Int J Eng Sci 12(1):5–19

Studer S, Welford R, Hills P (2006) Engaging Hong Kong businesses in environmental change: drivers and barriers. Bus Strategy Environ 15(6):416–431

Wang GH, Wang YX, Zhao T (2008) Analysis of interactions among barriers to energy saving in China. Energy Policy 36(6):1879–1889

Womack JP, Jones DT (1996) Lean thinking. Simon and Schuster, New York

Yang MGM, Hong P, Modi SB (2011) Impact of lean manufacturing and environmental management on business performance: an empirical study of manufacturing firms. Int J Prod Econ 129(2):251–261

Yuksel H (2008) An empirical evaluation of cleaner production practices in Turkey. J Clean Prod 16(S1):S50–S57

Zhang TZ (2000) Policy mechanisms to promote cleaner production in China. J Environ Sci Health 35(10):1989–1994

Zhang B, Bi J, Liu B (2009) Drivers and barriers to engage enterprises in environmental management initiatives in Suzhou Industrial Park, China. Front Environ Sci Eng China 3(2):210–220