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Identifying and ranking critical success factors for sustainable lean manufacturing implementation in automotive sector using (AHP) approach

Abstract

Sustainability has received significant attention of firms.by reducing resources wastes and increasing organizations' overall performance Small and medium size enterprises (SMEs) in manufacturing sector and developing economies are growing well and contributing a major proportion in total manufacturing yield. Past researches explored that lean manufacturing (LM) practices and sustainability can achieve excellent results by implementing them altogether. Hence, SMEs need to adopt sustainable lean manufacturing practices as this can address economic and environmental concerns together. However, the prior investigations have not thoroughly explored the success factors for sustainable LM implementation in SMEs. This provides the motivation for the present study. Thus, in this paper most relevant critical success factors (CSF) for sustainable lean manufacturing are identified with the help of existing literature and experts' opinions and further processed to investigate their relative importance applying an Analytical Hierarchy Process (AHP) technique. This study concludes with some managerial implications which will help the policy makers in government and industry to concentrate on couple of significant CSFs to encourage the sustainable lean manufacturing implementation in SMEs with minimum resource utilization.

Keywords: Critical Success Factor (CSF), Small and Medium Enterprises (SMEs), Analytical Hierarchy Process (AHP)

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1) Introduction:

SMEs are the key role players in the economic development of Pakistan (Syed, Ahmadani, Shaikh, & Shaikh, 2012) and defined as employment size up to 250 and annual turnover up to Rs. 250 Million (M. W. J. Khan & Khalique, 2014). SMEs have significant role in contributing to the economies and are taken as the lifeline of economic growth both for developing and developed nations. Like other developing nations, SMEs have a major share in Pakistan's economy (Khalique, Isa, Shaari, & Abdul, 2011). SMEs are 85 % of the manufacturing organizations and help to generate employment, enhance export, tax collection, income generation, innovativeness and competitiveness. (Fayyaz, Khan, & Mian, 2008),(Sardana & Dasanayka, 2007). Pakistan since its beginning experienced changing government policies. According to a survey manufacturing industry of Pakistan contributes 19% in the GDP. (Sarwar, Ehsan, Mirza, Azeem, & Ishaque, 2010)

Rapid industrial growth and the increased competitions globally have provided manufacturing SMEs great developmental opportunities and enhancement by cost reduction and quality upgradation. But that has also forced SMEs to follow the regulatory systems to manage their environmental responsibilities resulting in zero waste manufacturing (Tan, Shi, Tseng, & Cui, 2014). According to the facts and figures provided by the UNIDO, 90 percent businesses world-wide belongs to SMEs sector and facilitate approximately 60 percent employments around the world (N. R. Khan, Awang, & Zulkifli, 2013).

According to (Rinehart, Huxley, & Robertson, 2018), Lean Manufacturing (LM) will emerge as a world class manufacturing tool of the this century. The core strength of LM is its adeptness of zero waste approach and reduction in manufacturing cost and its thoroughly implementation can guide an industry to become a standard organization (Papadopoulou & Özbayrak, 2005). Lean manufacturing received much attention by researchers and practitioners after (Womack, Jones, & Roos, 1990) published the book entitled "The machine that changed the world". Being an recognized field of research, mostly researchers had focused their studies on lean performance, lean success factors and lean implementation (Bhasin & Burcher, 2006),(Martinez Sànchez & Pérez Pérez, 2001),(Shah & Ward, 2007). (Achanga, Shehab, Roy, & Nelder, 2006) and (Farris, Van Aken, Doolen, & Worley, 2009) highlighted the importance of CSFs for successful LM implementation. Since then, mainstream of LM researchers gave attention only on large manufacturers, and very little has been published with respect to LM implementation in SMEs (Achanga et al., 2006), (Martinez Sànchez & Pérez Pérez, 2001), (Ping-yu, 2009).

In developed countries with established policies and better infrastructure guarantee successful implementation of strategies such as LM and sustainability. However economies like Pakistan in developing phase are struggling for implementation of such strategies at initial stage as majority of the SMEs are facing lack of awareness on this approach and limited resources barrier (Shashank Thanki, Govindan, & Thakkar, 2016), (SJ Thanki & Thakkar, 2014). This sets a ground for industrial practitioners to think of economy specific custome made lean and sustainable approaches for implementation. The CSFs approach is a technique that helps managers to identify, specify and sort out among the most relevant and critical factors which determine a company's survival and its future success. The start of this technique was between the late 1970s and early 1980s, and for the twentieth century. At present, most of the previous studies on CSFs focused on successful implementation of lean manufacturing. (Habidin, Mohd Zubir, Mohd Fuzi, Md Latip, & Azman, 2018)

To address these issues, present study deals with identification and ranking of CSFs which posses strong influence on successful implementation of LM and sustainability in Pakistani manufacturing SMEs. Initially, 30 factors were explored from literature review for successful implementation of both LM and sustainability. On the basis of experts opinion these were reduced to 20 factors using majority rule approach (Li, Huang, Sun, & Li, 2019). Further, these factors were ranked by using analytical hierarchy process (AHP) tool.

The goal of this qualitative study is to facilitate leaders and policy makers at government level and industries concentrate and reflective understanding on few important CSFs to for sustainable LM implementation in SMEs with limited resources in automotive sector of Pakistan.

2) Literature Review

Focus of lean manufacturing (LM) is to eliminate all types of existing wastes within a manufacturing process by improving quality of products and process capability. SMEs are facilitated by LM adoption to become more productive by improving resource usage, less human efforts and on-time delivery to customers. A study conducted on 127 manufacturing firms, pointed that developing nations are still in struggling phase to implement LM. However, it was explored that measures towards LM implementation are already taken but there is slow progress due to inadequate training and knowledge, less working capital, obsolete technology, insufficient management skills.(Gandhi, Thanki, & Thakkar, 2018)

(Achanga et al., 2006) explored that leadership and financial resources are proven as the most vital factors for LM adoption in manufacturing SMEs. (Bakås, Govaert, & Van Landeghem, 2011) conducted a study on developed economies' SMEs and asserted that leadership commitment, employee involvement, change in organizational culture and employee empowerment play a key role in the successful implementation of LM. (Sangwan, 2011) conducted an exploratory study for identification of LM implementation factors in developing economies. (Rose, Deros, & Rahman, 2010) explored that strong leadership is the crucial factor for successful implementation of LM in SMEs amongst all others.

The linkage between lean and sustainability has been investigated by number of authors (Rothenberg, Pil, & Maxwell, 2001), (Azevedo, Carvalho, Duarte, & Cruz-Machado, 2012), (King & Lenox, 2001), (Kainuma & Tawara, 2006), (Mollenkopf, Stolze, Tate, & Ueltschy, 2010), (Alves & Alves, 2015), (Piercy & Rich, 2015). However there is not a single study has explored the relationship between LM practices and sustainability in manufacturing organizations. (Sajan, Shalij, Ramesh, & Augustine, 2017)

Identification of CSFs was the main objective of the study, which provided a basis for this research that dealt with the CSFs identification in lean manufacturing sustainability were adopted to conduct a comprehensive literature review and expert's opinion It is resulted in 20 CSFs enlisted and presented in Table 1, which have been grouped into five dimensions depending on their properties Table 1 also illustrates brief explanation of each factor and related references.

Table 1. Critical success factors of sustainable lean manufacturing

Dimension	Factors	Explanation	References
Production Management (G1)	Feasible lean practices (F1)	The best practices implemented with organization's existing resources and recommended by customers, employees and consultants	(A. N. M. Rose, Deros, & Rahman, 2014)
	Quality management (F2)	Everyone in the organization is responsible and accountable for quality using process control tools for product and process quality	(Achanga et al., 2006)
	Supply Chain Management(F3)	Organizations improve their performance by concentrating on supply chain management and its processes and focused by researchers too. This strategic viewpoint has been adopted in automotive industry.	(Habidin et al., 2018)
	External Management and Involvement (F4)	Information and feedback from customers on quality performance and guidance on lean implementation while suppliers provide quality raw material and components	(A. N. M. Rose et al., 2014)
Environmental Management (G2)	Environmental Management (F5)	Knowledge about environmental impacts gives insight for sustainable system, and it provides a clear knowledge upon designing the complete process of product life cycle	(Vinodh, Ramesh, & Arun, 2016)
	Sustainable Manufacturing (F6)	It enables the development of environment friendly processes and products which reduce their impact to environment	(Thirupathi & Vinodh, 2016)
	Waste Management (F7)	To enhance environmental outcome and sustainability through minimizing the impacts of material flow, and through recycling, reuse, reduction of energy and material waste.	(Raj, Ma, Gam, & Banning, 2017),(Carter & Carter, 1998)
	Green production (F8)	Environmental impacts are systematically examined to this assessment measures are developed and implemented	(Vinodh et al., 2016)
Top management involvement (G3)	Performance management (F9)	A strategic business plan implementation provides directional change for the organization including culture, motivation policies. The effectiveness and efficiency of the process followed to meet yearly and customer targets.	(Thirupathi & Vinodh, 2016)
	Management commitment and leadership (F10)	A successful lean manufacturing needs to be fully supported by senior management; which is the most effective driving force for an organization to carry out lean manufacturing	(Achanga et al., 2006) , (Ismail Salaheldin, 2005), (Motwani, 2003)
	Training & Education (F11)	Training for employees and management itself and educate them for ongoing processes. It is essential to deliver the main concepts and techniques of LM. Increase awareness about lean concepts and lean benefits	(Singh Sangwan, Bhamu, & Mehta, 2014) , (A. N. M. Rose et al., 2014) , (Achanga et al., 2006) ,
	Human resource management (F12)	HRM focus on importance of recruiting, compensation, promotion and training in the success of LM. Motivated skilled workers contribute effectively in LM implementation.	(Lin & Ho, 2008) ,(A. N. M. Rose et al., 2014)

Corporate social responsibility (G4)	Social Responsibility (F13)	Social responsibility is significant for business society, which is the most responsible factor for socio economic and environmental problems and to provide efficient solutions for the more sustainable future.	(Sila & Ebrahimpour, 2003) ,(Habidin et al., 2018)
	Organizational culture (F14)	Organizational culture is one group of people's behavior and attitude. Lean culture means to change employee's behavior, emotion and political process for organizational success	(Singh Sangwan et al., 2014), (A. N. M. Rose et al., 2014), (Motwani, 2003)
	Effective communication (F15)	To communicate, to inform and to discuss about LM implementation, to listen to employees and to explain the needs of change, clarifying and developing a shared comprehension of goals	(Ismail Salaheldin, 2005) , (Motwani, 2003) , (Yauch & Steudel, 2002)
	Social wellbeing (F16)	Human safety and societal benefits, while at workplace level is workers safety, health, work place illumination and noise control for local community it is workers' insurance and compensation, complying with laws and regulations related to workforce	(Thirupathi & Vinodh, 2016)
Employee Management (G5)	Research & development (F17)	New product sales as percent of total sales, active patents, product introduction policies held by the organization, also the cost reduction by improving product and process techniques using value analysis methods.	(Thirupathi & Vinodh, 2016)
	Continuous Improvement (F18)	Continuous improvement in work related processes and applying creativity to improve process flow leads to sustainability in lean manufacturing implementation	(Achanga et al., 2006), (Sila & Ebrahimpour, 2003)
	Employee involvement (F19)	Employee involvement is a prerequisite for successful lean sustainable and lean manufacturing implementation and can be ensured by enhancing the competencies of employees towards jobs, evolving the environment of equipment and system ownership by the employees.	(Achanga et al., 2006) , (Ismail Salaheldin, 2005)
	Empowerment of Employee (F20)	For establishing and implementing the vision of organization, individuals are involved at every stage. The decision process is decentralized and the responsibility is distributed in order to stimulate individuals to own the positive change	(Singh Sangwan et al., 2014) , (A. N. M. Rose et al., 2014)

3) Research methodology

Majority rule approach was applied to the identified CSFs and reduced to 20 factors by eleven experts. Further Analytical Hierarchy Process (AHP). was used to gain deeper understanding of the 20 CSFs by using another panel of 10 respondents from industry and academia with expertise in manufacturing sector. This technique was used to allocate weights to each factor and assess their relative significance properly. Although this techniques is more than three decade's old, the merits of adaptability and strength has made it to be applied extensively in many domains (Khalil, Kamaruzzaman, & Baharum, 2016).

Selection of experts for factors selection

A panel of eleven experts comprising three experts from academia and eight practitioners from automotive industry with more than 10 years of work experience were invited to participate in the study to make the judgments among selected CSFs. Prior to making the decisions, number of experts were counseled to make it certain that the questions were properly stated and developed. Here the judgements of selected experts were considered valid due to their association with recognized organizations.

3.1) Analytical hierarchy process

AHP is an organized tool to deal with complex decision problems and was created by Saaty (Wind & Saaty, 1980). AHP is a decision-making technique that assigns priorities to alternatives when multiple criteria are to be considered and thus decision maker are allowed to create hierarchical structure and rank the criteria for complex problems .(Singh, Kansara, & Vishwakarma, 2018)

Now a day decision making has become a mathematical science for which information is gathered to understand the situation so that good judgements can be developed (Figueira, Greco, & Ehrgott, 2005). Based on information gathered, we act as decision makers to get some conclusion either consciously or unconsciously in daily life (Saaty, 2008). In decision making, tangibles and intangibles are needed to be trade off. For this purpose, both have to be measured alongside. However, decision maker wants to control the process by choosing the experts or influencing the rules behind decisions. Multi-criteria methods of decision support may be used to solve such issues (Adamus, 2009).

AHP is a simple decision-making tool that deal with complex, unstructured and multi-attribute problems (Albayrak & Erensal, 2004). The method is based on a theory of measurement through pairwise comparisons relies on the judgement of experts to derive the priority scales. These scales measure the intangibles and tangibles in relative terms using as scale of absolute judgement. It represents that how much one element dominates another with respect to a given attribute (Saaty, 2008).

3.1.1) Basic steps of AHP

The complete process of AHP has been explained here that consists of the following steps:

3.1.1.1) Define the objective

First step includes the brief explanation of research objective by defining the problem.

3.1.1.2) Develop hierarchy of problem

According to the study objective and problem definition, this step structures the decision hierarchy from top with goal of the decision through the intermediate levels to the lowest level. Intermediate levels are the criteria or sub-criteria on which consequent level depends while lowest level is a set of alternatives (Saaty, 2008).

3.1.1.3) Select experts for assessment

For assessment of factors according to the defined problem, experts, researchers, and practitioners are selected from the relevant field as decision makers. Process is conducted through pairwise comparison of each element and decision makers must express their preferences between each pair of elements.

3.1.1.4) Construct pairwise comparison matrix

This step construct pairwise matrix by comparing each element of same level with respect to the objectives. For this purpose, opinion of decision markers or experts are solicited based on fundamental preference scale (Table 2) to develop a judgement matrix.

Table 2: The fundamental preference scale of absolute numbers

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one activity over another
5	Strong importance	Experience and judgement strongly favor one activity over another
7	Very strong demonstrated importance	An activity if favored very strongly over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediately	Used to represent compromises between the preferences in weights 1,3,5,7 and 9
Reciprocals	Opposites	Used for inverse comparison

Source: (Saaty, 2008)

This process starts from second level (first level of criteria) and finishes at alternatives. In each level, the elements are compared pairwise according to their levels of influence and based on the specified element in the higher level. The final pairwise judgement matrix (A) of each level is developed as follows:

$$A = \begin{bmatrix} 1 & a_{12} & \dots a_{1n} \\ 1/a_{21} & 1 & \dots a_{2n} \\ \vdots & \vdots & \vdots \ \vdots \\ 1/a_{n1} & 1/a_{n2} & \dots \ 1 \end{bmatrix}$$

where, $a_{ij} = \begin{cases} 1 & if\ i = j \\ 1\ to\ 9, or\ 1^{-1}\ to\ 9^{-1}, & if\ i \neq j \end{cases}$

3.1.1.5) Synthesize and construct priority

After formation of judgment matrix, the mathematical process commences in order to normalize each matrix and finally determine the priority weight for each element of matrix. For normalization, each entry in the column of pairwise matrix is divided by the sum of each column. Finally, corresponding ratings of each element (Eigenvector) of matrix is determined by averaging all the values in each row follows:

$$A = \frac{\begin{bmatrix} 1 & a_{12} & \dots a_{1n} \\ {a_{21}}^{-1} & 1 & \dots a_{2n} \\ \vdots & \vdots & \vdots \ \vdots \\ {a_{n1}}^{-1} & {a_{n2}}^{-1} & \dots \ 1 \end{bmatrix}}{S_{C1} \quad S_{C2} \quad \dots \quad S_{Cn}}$$

$$N = \begin{bmatrix} \frac{1}{S_{C1}} & \frac{a_{12}}{S_{C2}} & \frac{a_{1n}}{S_{Cn}} \\ \frac{{a_{21}}^{-1}}{S_{C1}} & \frac{1}{S_{C2}} & \dots \frac{a_{2n}}{S_{Cn}} \\ \vdots & \vdots & \dots \ \vdots \\ \frac{{a_{n1}}^{-1}}{S_{C1}} & \frac{{a_{n2}}^{-1}}{S_{C2}} & \frac{1}{S_{Cn}} \end{bmatrix} \qquad X = \begin{bmatrix} \frac{\sum Row\ 1}{n} \\ \frac{\sum Row\ 2}{n} \\ \vdots \\ \frac{\sum Row\ n}{n} \end{bmatrix}$$

After this, the largest eigenvalue λ_{max}, known as principle eigenvalue, will be determined by summation of the products of eigenvector and sum of the columns of the reciprocal matrix A. This value can be used further for consistency test.

$$\lambda_{max} = \sum_{i=1}^{n} S_{Ci} \times X_i$$

3.1.1.6) Consistency test

The quality of the output from AHP is related to the consistency of the judgement by experts. Saaty suggests a process for checking the result consistency based on consistency ration (CR). The CR value above 0.10 indicate that elements are not compared properly and experts need to review the comparison stage. The CR values is determined by consistency index (CI) and random index (RI).

$$CR = \frac{CI}{RI}$$

The Eigenvector method results a natural measure for consistency index that utilized the value of λ_{max}. By normalizing this λ_{max} calculated by the size of matrix, Saaty defines the value of CI as:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

For each size of matrix n, random matrices were calculated and their mean CI values called random index was computed (Table 3). Using these values, the CR is defined as the ratios of RI and CI. Thus, CR is a measure of how a provided matrix compares to a purely random matrix (Golden, Wasil, & Harker, 2003)

Table 3: Random inconsistency index (R.I.)

N	1	2	3	4	5	6	7	8	9	10
Random consistency index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source:(Golden et al., 2003)

The matrix is reflected to be consistent with the CR less than 0.1. If the CR is greater than 0.1, the comparison matrix is measured as inconsistent and it needs to be reviewed. (Song, Li, List, Deng, & Lu, 2017)

3.1.1.7) Calculate the priority weight for each factor

Calculate the weight of each factor. The preferences obtained from the comparisons are used to weight the preferences in the next level for every factor. The process continues to obtain the normalized principal eigenvectors, which give the weights for each factor.

The survey is to be naturally followed by the aggregation of individual judgments (AIJ), the construction of a matrix representing a group decision.

$$a_{ij}^{group} = \sqrt[N]{a_{ij}^{Participant\ 1} \times a_{ij}^{Participant\ 2} \times \cdots \times a_{ij}^{Participant\ N}}$$

Where N is the number of participants (Ramanathan & Ganesh, 1994), (Saaty & Shang, 2007)

This procedure is called the row geometric mean method (RGMM), in contrast with the weighted geometric mean method (WGMM), which gives different weight factors according to the importance of the participants. The RGMM method is used in this study because all of the participants are treated as equal.

3.2) Data collection

Experts from academia and industry with the appropriate knowledge and experience were contacted to judge the appropriateness of proposed criteria, sub criteria concise through the literature review. After discussion, a total of seven industrial practitioners and three academicians with thorough knowledge and deeper perception of lean manufacturing and sustainability patterns were invited to take part and fill out the questionnaire to deliver decision on the relative significance of the criteria and sub-criteria.

The AHP methodology may be impractical with large sample size as respondents may have a great tendency to provide arbitrary answers which may lead to high degree of inconsistency (Wong & Li, 2008). In this study a sample sizes of 10 respondents was used. Using the responses from the experts, finally, 20 representative factors were selected for sustainable LM implementation and these factors were identified; see Table 1. Because of the interdisciplinary property, these factors were selected by majority rule; that is, a factor was discarded if experts from two or more categories questioned its representativeness and placed in five dimensions based on their properties and attributes.

4) Results and Discussion

This study provides ranking order to all the selected 20 factors by using AHP on the basis of expert opinion. There were five dimensions placed at criteria level. The success factors (F1-F20) were placed at sub-criteria level and there was no substitute at the bottom line. Pairwise judgement of the factors was used with a standard 1–9 scale given in Table 2 constructed on the question that with reverence to a given dimension, and with the objective of sustainable lean manufacturing implementation. The geometric mean values of all experts' judgments was used and made equivalent to nearest integer to obtain the importance value of each pair factors(Escobar, Aguarón, & Moreno-Jiménez, 2004). Ultimately, an allocated and normalized weight of each factor was drawn as shown in Table 4. These weights assign the importance of the factor itself. From the second row of Table 4, it was observed that top management involvement dimension ranked first in the criteria level securing a weight of 0.350439. With weightage of 0.19167, Production Management dimension rank second, followed by employee management dimension given with an evaluation of 0.182597. The weights for the remaining dimensions are 0.119159 (corporate social responsibility) and 0.182597 (employee management). The ranks of the 20 success factors in the sub-criteria level are shown in the last column of Table 4. Values of consistency index (CI) and consistency ratio (CR) of all the observations derived from calculations were placed in column 7 and 8 of Table 4. As all the CR values are less than 0.1, which indicates that all the relative weightage values are consistent. (Saaty, 1990)

Table 4. The importance weights of all factors

Factors	Group1	Group2	Group3	Group4	Group5	CI	CR	Weight	Rank
	0.19167	0.106891	0.350439	0.119159	0.182597				
F1	0.27897					0.044791	0.056354	0.05347	7
F2	0.393033							0.075333	2
F3	0.104462							0.020022	13
F4	0.076934							0.014746	16

F5		0.229932						0.024578	18
F6		0.092743				0.041852	0.050327	0.009913	20
F7		0.427685						0.045716	11
F8		0.107425						0.011483	19
F9			0.066478					0.023297	10
F10			0.524721			0.043458	0.05592	0.183883	1
F11			0.166102					0.058208	4
F12			0.202515					0.070969	3
F13				0.156725				0.018675	15
F14				0.342769		0.041419	0.046021	0.040844	9
F15				0.20978				0.024997	12
F16				0.16265				0.019381	14
F17					0.06577			0.012009	17
F18					0.299992	0.039654	0.044059	0.054777	5
F19					0.230082			0.042012	8
F20					0.297258			0.054278	6

5) Conclusion

The purpose of this study was the identification and ranking of CSFs for sustainable LM implementation which play a decision role both for leanness and sustainability in Pakistani automotive manufacturing SMEs. Initially 30 CSFs were identified and filtered through literature review and reduced to 20 after experts' decision of majority vote. Further, these CSFs are grouped into five categories and prioritized using AHP to determine key factors for successful implementation. AHP was used to rank the factors according to their global weights. Top management commitment appeared as a key factor of implementation in this study which got a strong support from the literature as well.

However, this study facilitates the managers to select most vital CSFs for implementation. This study is limited to SMEs within the automotive manufacturing sector and application may differ in other sectors.

Future researches can be managed by examining relations between the factors which can be studied using modeling techniques such as interpretive structural modeling and can be validated through structural equation modelling. Model development for sustainable LM implementation can be a future dimension for researchers.

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