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A framework for implementing sustainable lean manufacturing in the electrical and electronics component manufacturing industry: An emerging economies country perspective

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ABSTRACT

The survival of the manufacturing industry has been faced with multiple challenges due to changing stakeholder requirements, global competition and pressure to integrate sustainability practices. Lean manufacturing has proven positive relevance in enhancing the sustainability and operational economic performance of manufacturing industries by eliminating the non-value added operations. The growth of the Even with the rapidly growth Electrical and Electronics Component Manufacturing (EECM) is experiencing, its sustainability performance has remained an unexplored avenue. In this context, the present study aims to examine the 'critical success factors (CSFs)' for implementing sustainable lean manufacturing (SLM) in the Indian EECM organization through a hybrid multi-criteria decision-making technique. A total of 40 CSFs representing Management, Workforce, Operational and Knowledge factors were collected through extant literature and expert opinion. The collected factors were shortlisted using 'Complex Proportional Assessment (COPRAS)' method based on their ease of collecting data. The findings provided 20 CSFs under management, workforce, operational, and knowledge criteria, which will facilitate the EECM organization for implementing SLM. The shortlisted CSFs were prioritized using Best-Worst Method (BWM) to identify the most crucial CSF. "Top-management commitment", "internal expertise" and "employee involvement" were identified to be the top three CSFs. Involvement of top-management was found to have direct impact on working culture and competitive advantage of the organization over the competitors.

1. Introduction

Increasing global awareness about sustainability and the pressure to integrated sustainable development goals in manufacturing industries is reforming the conventional production techniques to attain a heightened level of triple-bottom line performance (Gopal and Thakkar, 2016). India's per capita emission of CO_2 was 1.6 tonnes, while its share in total global CO_2 emission was estimated to be 6.4% (India, 2020, report published by International Energy Agency). The environmental impact caused by manufacturing industries has started forcing the organizations to expand their metrics of performance from economic aspect towards environmental aspect. The pressure from stakeholders and international market scenario is further pushing the industries in the South Asian region like India and China to adopt sustainable practices in their manufacturing system (Dwivedi et al., 2019; Chen et al., 2020). Thus, sustainability and lean are becoming the benchmark for the manufacturing sector.

According to 'Indian Manufacturing Industry Analysis' report published by IBEF in October 2020, among all the manufacturing sectors, the electronic component manufacturing is identified to be one of the fast growing industries. A growth rate of 32% has been targeted globally for the sector over the next five years. The 'National Policy on Electronics' report (NPE, 2019) estimates India's share in the global hardware electronic component production was about 3% during 2019–20. The constant growth in customer base and the rising demand for consumer durables have provided enough scope for the growth of the Indian

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electronics industry, it is both an opportunity and a challenge for the country. To tackle such a situation, the government is focusing to gear up the production rate within the country in every possible way and further aiming in promoting export of electronic goods to attract larger investments. Apart from that, electronics hardware manufacturing has been included among the 25 pillars of 'Make in India' and 'Digital India' campaign. This extreme stipulation noticed from above data enforces the Electrical and Electronics Component Manufacturing (EECM) industries to streamline new techniques in their production system to survive and tackle the challenges. Meeting such huge demand with admissible quality will also heighten the requirement of manpower, material, investment and all sorts of resources along with equivalent environmental degradation which, in turn, imposes a set of constraints on the industries (Dave and Sohani, 2019). The industries aim to minimize resource utilization while being sustainable in their operations.

This demands for the inclusion of sustainable lean manufacturing (SLM). Lean manufacturing is an integrated system composed of many inter-related elements whose main aim is to eliminate waste by reducing or minimizing variability related to supply, processing time, and demand (Shah and Ward, 2003). The major focus of lean is making changes in the processes and striving for continuous improvement which eliminates activities that do not add any value in the production system (Venugopal and Saleeshya, 2019). Lean manufacturing provides a great improvement in productivity when implemented in an integrated way (Panwar et al., 2018). Reducing the waste using lean tool can help the organization in deploying lean manufacturing (Logesh and Balaji, 2020).

The adoption of SLM fundamentally differs from the adoption of sustainable manufacturing. Sustainable manufacturing is the creation of manufactured products through economically-sound processes that minimize negative environmental impacts and maximises social welfare. Lean manufacturing, on the other hand, is based on an ideology of maximising productivity while simultaneously minimising waste within a manufacturing operation. An emphasis on sustainability and lean together in SLM can improve the performance of an organisation and build on lean manufacturing programs by extending the emphasis on waste elimination and the involvement of employees in improvement initiatives. In practice, adopting sustainability into manufacturing process is a challenging task. Especially for developing countries, integrating social and environmental aspects with business goals is a gritty process when compared to developed countries (Malek and Desai, 2019). Unpreparedness and absence of adequate knowledge are the major reasons for failure while trying to implement a new technique (Liao et al., 2017). Knowing the key enablers can serve as a catalyst in successful implementation of the new strategies (Kaswan and Rathi, 2019). The identification and prioritization of the critical success factors (CSFs) which enable the implementation of SLM will to guide the transformation process and make it efficient and successful. Lean manufacturing focuses on reducing costs by eliminating wastes and non-value-added activities, while sustainability aims in environmental protection and providing equity to the employees. The inclusion of SLM will aim to improve efficiency by freeing up employees and resources for innovation and quality control that would have previously been wasted. Thus, the identification of CSF for implanting SLM is an essential step in Indian EECM industries.

To manoeuvre the above mentioned requirements, the need for implementing sustainable lean principles becomes inevitable. For this purpose, the EECM industries have to be studied for recognizing the CSFs. Based on above discussion, the present study deals with the following research questions:

- What are the pillars/components of CSFs which can be applied for SLM adoption in Indian industries?
- How can the CSFs be evaluated to determine the priority to support SLM?

In practice, adopting sustainability into manufacturing industries is a challenging task mainly for developing countries. Lack of resources and absence of adequate knowledge are the major hurdles for reluctance of the industries to implement a SLM. Knowing the key enablers can serve as a catalyst in successful implementation of the new strategies. With reference to the above problems, this study aims at presenting the CSFs which are vital for implementing sustainable lean in EECM industry using a hybrid MCDM approach. In an attempt to answer the research questions, a detailed literature review was carried out to identify the pillar or component of CSFs which are termed as the critical factors. A total of 40 CSFs representing Management (M), Workforce (W), Operational (O) and Knowledge (K) factors were collected. Further, the CSFs are ranked using hybrid MCDM technique comprising Complex Proportional Assessment (COPRAS) for shortlisting and Best-Worst Method (BWM) through industrial experts' judgments. The collected factors were shortlisted using 'Complex Proportional Assessment (COPRAS)' method based on their ease of collecting data. The shortlisted CSFs were prioritized using Best-Worst Method (BWM) to identify the most crucial CSF. Through the prioritization, partial induction of SLM in industries can be also possible for any industry.

The paper proceeds further in the following sequence of contents. The review of literature done on sustainable lean in global, Indian and electronics manufacturing background is explained in section 2. Section 3 provides the case explanation followed by the hybrid MCDM methodology employed in the study and its standard procedure. The data analysis of case organization where the study was conducted and implementation of the methodology are presented in section 4. The final result obtained and discussion on the result are illustrated in section 5. Finally, the conclusion and limitation of the study is presented in section 6.

2. Literature review

In this section the evolution, benefits and current status of sustainable lean practices in manufacturing industries are explored through the past literature. This section comprises two subsections, explaining sustainable lean in global scenario, in Indian context and in terms of EECM industry.

2.1. Sustainable lean in global scenario

The significance and positive impact of implementing lean practices in organization's performance have been explored by many researches, investigating the impact of lean methods over the individual entities of triple bottom line. Chiarini (2014) investigated the efficacy of lean production tools in reducing the environmental impacts caused by the manufacturing companies. Faulkner and Badurdeen (2014) analysed the mapping of the ecological and societal impact as a means of enhancing sustainability in manufacturing industry. The paper analysed metrices which made the manufacturing more lean by focusing on the potential areas for continuous improvement. The study by Caldera et al. (2017) studied the role of lean thinking in sustainable business practices and provided a new strategy called 'regenerative development' with the nine key characteristics regarding to small and medium enterprises (SMEs) in Australian background. Garza-Reyes et al. (2018) and Dieste et al. (2019) established positive relationship between lean methods and environmental performance. Lean tools like TPM, TQM and JIT were found to have the strongest significance on environmental performance. Segura et al. (2019) analyzed the lean manufacturing strategy with respect to its impact on business performance using a system dynamics based methodology. The findings provided guidelines for assessing the organization's business performance and explained the impact of lean in short and long-run conditions.

As lean was found to be an efficient technique to improve operational performance of the organizations, its role in environmental performance and people satisfaction which includes workforce, customers and all stakeholders remained vague initially. Later, the escalating impact induced by manufacturing organizations on the planet and society revealed that improvement in operational performance alone won't help the organizations to become sustainable. In the view of overcoming this challenge, an upswing in triple bottom line, i.e. principles which benefits society, environment and economy in manufacturing grabbed the focus. Bhattacharya et al. (2019) conducted a systematic literature review and highlighted the integrating factors of lean-green as waste reduction, efficiency development, continuous improvement and quality management. The study also notified that the impact of lean-green on sustainability performance is non-linear in nature depending on the dimension. Farias et al. (2019) studied how integrated lean-green practices can be used for performance assessment. The study proposed a framework for evaluating operational and environmental performance of the organization. Helleno et al. (2017) integrated a new set of sustainability indicators with lean manufacturing tool (VSM) to provide a method for assessing organization's performance. Case studies with the proposed method recognized different levels of sustainability performance in Brazilian industries. The paper by Siegel et al. (2019) combined green lean approach and sustainability for SMEs. The study claimed that the most common challenge in SMEs in adopting lean green was lack of metrics and measurement. Globalization has played a crucial role in China's inclusion of sustainability in lean manufacturing (Tong and Huatuco, 2018). The inclusion of SLM will enhance the ecological and business performance, by ensuring the channel partners across globe are also sustainable and lean as in case of China's manufacturing industries (Zhan et al., 2018). In fact, lean and green deployment system, considering companies' needs for survival and short-term profitability in manufacturing sector of China (Fu et al., 2017). The construction industries in china are at forefront in incorporating the lean principles to be more sustainable and resilient (Li et al. 2020a, 2020b).

All the studies combining different aspects of sustainability supported the fact that lean correlates in sustainable development from worldwide researches. It can be observed that the focus on the literature on identifying the CSF in emerging economy such as India is negligible, which is the motivation of the current paper. The constructive welfare brought by undertaking the lean practices in view of attaining sustainability is a revolutionary paradigm which is being studied largely in the recent years. But identifying the overlapping and conflicting areas for lean and sustainability was a tricky task to be dealt with. Caldera et al. (2017) studied the role of lean thinking in sustainable business practices and provided a new strategy called 'regenerative development' with the nine key characteristics regarding to SMEs in Australian background. Garza-Reyes et al. (2018). Wong et al. (2018) tested the effects of sustainable development of supply chains on cost-reduction (lean), environmental (green) and financial (profitable) performance. Results showed that sustainable development positively affect each performance of the organization. Dey et al. (2019) investigated the impact of sustainability practices, lean practices (LP) and process innovation (PI) in achieving sustainability performance in SMEs. The result showed the mediating effect of LP is more when compared with PI. The investigations on finding the relationship among lean and sustainability further narrowed down with identifying potential barriers and enablers. This was because, knowing the barriers will help in where to be cautious and knowing the enablers will help in where to focus while trying to implement a new manufacturing philosophy.

From the analysis of the literature, it becomes obvious that sustainable lean is a manufacturing philosophy which was proved to improvise organization's performance in terms of productivity, people satisfaction and environmental prevention (Liao and Wang, 2021). But a definite method or solution proposed from any country may or may not be effective for the whole globe, since each country has their own government environmental policies, regulations and people culture (Govindan et al., 2014). With this motive many Indian researchers have carried out studies in view of extending sustainable manufacturing practices into electronics manufacturing industry in India. Vinodh et al. (2013) analyzed the tools for sustainable lean and ranked them using compromise ranking approach in a modular switch manufacturing organization. The study suggested life cycle impact assessment (LCIA) as the best SL tool. Agrawal et al. (2014) developed a model for forecasting return of product to the company for recycling in Indian electronics industry. The findings suggested Graphical Evaluation and Review Technique (GERT) to be an effective tool for forecasting the product return. Gupta et al. (2015) developed an AHP- based model with the key sustainability practices and ranked them based on scores by assessing the relationship between manufacturing practices used and sustainability performance in electrical panel industry from India. Logesh and Balaji (2020) made an experimental investigation to implement green manufacturing by reducing waste generation using lean tools in an electrical component manufacturing company. Lean tools like *kanban*, *takt-time*, single minute exchange of dies, kaizen were employed and the data collected before and after deploying the lean tools showed results with improved resource utilization by reducing waste. It can be seen that the literature has delved upon the interaction between lean manufacturing and sustainability, however, the concept of identifying the CSF which enable the integration of sustainability and lean practices in Indian EECM sector is lacking in the literature.

2.2. Sustainable lean in Indian background

India, being a country with huge workforce and natural resource availability is growing as an important manufacturing hub over the past years. To meet the huge demand with expected quality and balanced capacity utilization, industries are changing conventional operating practices with new techniques. Studies regarding implementation of lean manufacturing and sustainability in Indian context have gained momentum in the past years. Vimal and Vinodh (2013) made practical studies before and after implementing lean in an industry and established the reduction in environmental impact after implementation of lean practice. Sajan et al. (2017) investigated and established the positive linkage between lean manufacturing practices and sustainability performances in Indian SMEs and also tested the relationship among the triple bottom line entities. Dave and Sohani (2019) studied the association between implementing lean practices and overall productivity of the organization in central India based industries. The findings established that adopting lean practices is mandatory for improving overall productivity and following island approach is suggested to be unsupportive. Thanki and Thakkar (2019) investigated influence of lean-green practices on organization's operational and environmental performance in Indian SMEs. The study suggested that the performance enhancement can be achieved practically through strategies like lean-green rather than reducing the operational size. Dwivedi et al. (2019) studied and identified the interactive connection among the key performance indicators (KPIs) which can assist implementation of sustainable manufacturing practices in Indian leather industry. Swarnakar et al. (2020) integrated lean tool (VSM) with various sustainability indicators and proposed a model to assess the manufacturing process under three dimensions of sustainability. The above mentioned inferences exhibit lean-sustainability relationship in Indian context. It can be seen that focus on the researchers are more towards the SMEs and small scale businesses, a wholistic picture of a manufacturing sector is however, missing.

The literature has also delved upon the identification of the CSF and enablers is extensive with focus on lean or sustainable practices. Thirupathi and Vinodh (2016) employed a hybrid modelling technique to analyze the sustainable manufacturing factors in Indian automotive component sector and established the existing structural relationship. Jadhav et al. (2014) developed a framework for sustainable lean implementation in which the lean practices were modelled establishing powerful driving and dependence factors. Luthra et al. (2018) modelled the critical success factors for sustainability initiatives in supply chain in automotive background. The relationship among the CSFs were established from which 'Government Legalisation' has been found to be the most influential factor and 'Community Welfare and Development' is the most easily influenced factor. Toke and Kalpande (2019) identified critical success factors of green manufacturing for achieving sustainability from the data collected from automobile, refrigeration and electrical component manufacturing industries. Top management commitment and societal concern for protection of natural environment got top two weightage of all the factors. The relationship between lean practice and sustainability performance was studied by a large number of authors and the integrating and overlapping areas were identified in Indian background (Cherrafi et al., 2016; Mellado and Lou, 2020). But the problem is that the practitioners were unable to figure out where to focus for achieving such a business performance from the mathematical perspective is missing. Most of the literature have concentrated on empirical studies and hypothesis testing while there is lack of analysing the quantitative relationships with the help of decision maker opinion which is the highlight of the present work.

The implementation of SLM practices is essential in the upcoming years for all manufacturing industries to be successful in the dynamic market (Singh et al., 2021). Each manufacturing sector involves its own operating procedures and production techniques, the strategy for each industry varies accordingly. So the findings established for implementing SLM in a specific industry may not be effective in other industries when it comes to application. The EECM which produces products in wide range of variety on a huge scale needs to be studied exclusively. Doolen and Hacker (2005) developed a lean assessment instrument with available tools and conducted an exploratory study to assess the performance of an electronic manufacturing industry. The research suggested size of organization and type of manufacturing as significant factors in impacting the results for implementing lean. Lindgreen et al. (2009) studied the status of supply management and corporate social responsibility in Korean electronics industry. The outcome showed that the pressure and standards on social aspect were not accepted and implemented as on environmental aspect. Govindan et al. (2013) studied and established the green supply chain management tools for electronics industry in Brazilian background which will improve environmental performance. Commitment of senior managers and cooperation with customers were found to lead the other practices. Hsu and Chang (2017) used DEMATEL method and identified the critical success factors and related best practices for the emerging electronics industry to get included in Dow Jones Sustainability Index. Fantazy et al. (2019) explored how the impact of culture of competitiveness and knowledge development of a firm is related to sustainable supply chain management. The results established positive relationship. Sellitto et al. (2019) investigated the efficiency of green practices in enhancing organization's competitiveness by including three factors influenced by the constructs that facilitate construction of competitiveness. Banik et al. (2020) examined the critical success factors for green supply chain management in Bangladesh-based electronic industry. Vinodh (2020) identified barriers in adopting lean practices in an electronic component manufacturer. The inter-relationship among barriers were established using TISM tool. From the above researches, it can be seen that the performance improvement in EECM sector through adoption of lean and sustainability concepts is not explored together. The literature has much focused on understanding the lean concepts and the SLM aspect is still missing. Moreover, the use of hybrid methodology to reduce the factors based on certain attributes related to information gathering and further prioritization of these factor is not carried out in literature.

2.3. Research gap

The above literature reveals that studies related to environmental (green) performance improvement and investigation of the practices and tools of sustainability in EECM industry is missing in literature. The studies have focused more on implementing sustainable or lean practices. The integration of sustainability and lean concepts as SLM was not carried out for the mentioned sector in Indian context. Also, all the past studies exploring the CSFs for other industries or for electronic industries in other countries have a common property of selecting the factors for study based only on past literature and expert opinion. No study was found to have employed analytical tools to critically evaluate the significance of the available factors in terms of sustainability before studying them. Since selecting the factors through expert discussion is a qualitative method, the reliability of the process can't be rationalized as the linguistic variables do not have standard representation. A quantitative method which records an equivalent numerical value for the linguistic opinion of the expert can overcome the above drawback. Hence, a research involving identification of CSFs and ranking them with appropriate analytical tool must be applied to provide a clear picture to the management and practitioners and help them where to focus for successful implementation of SLM. All the above mentioned research gaps justify the purpose of this study.

With reference to the above problems, this study aims at presenting the CSFs which are vital for implementing sustainable lean in EECM industry using a hybrid MCDM approach. In this view, the factors collected from past literature were subjected to evaluation based on sustainability aspects and complexity for organization followed by prioritizing the identified factors.

3. Research framework

The study has been undertaken in an electronic component manufacturing organization situated in Tamil Nadu, India. Organization ABC is a large manufacturer of installation systems for the electrical infrastructure of buildings and facilities with a large variety of products and services. The organization is said to be the world leader in the cable support and lightning protection systems. It manufactures and supplies products like surge protection systems, earthing systems and junction box etc. The case organization has already implemented the concept of 'lean manufacturing' successfully. In order to face the global market, safe handling of toxic and hazardous raw materials involved in production and ensure the quality constantly, the organization is continuously seeking for appropriate techniques and better manufacturing principles which could bring improvement to the company as well as to the society. Also, increase in e-waste production is becoming a major challenge and demands immediate actions. Having all this dimensions in consideration, the organization is concerned in incorporating sustainability in their manufacturing process. The organization wants to understand how to integrate the sustainability factor in lean manufacturing Thus the foremost step in this direction is to know the CSF for them to achieve sustainable lean manufacturing (SLM). The understanding of the pillars/components of CSFs which can be applied for SLM adoption in Indian industries is a crucial aspect for the decision makers.

3.1. Identification of the CSFs from literature

It is evident from the literature that researchers have analysed the lean and sustainability paradigms in the literature, however SLM is still lacking. There is clear lack of integration of SLM in EECM industries. To understand the SLM integration there is need to identify and prioritize the CSFs, which is motivation for the current study. Initially, we did systematic literature review by using the terms. The various CSFs for the integration of lean and sustainability in EECM were identified through an extensive literature survey. Initially, the research papers were collected from reputable databases such as Science Direct, Springer, Elsevier, Emerald, Taylor & Francis, SAGE, etc. The keywords used for the research were 'critical success factors', 'sustainable supply chain management', 'lean supply chain', 'Electrical and Electronics Component Manufacturing'. In these databases, we narrowed our search by assessing peer-reviewed journals in the field of supply chain management. Through this process, we identified the CSF for SLM in business operations. Based on this detailed survey of the extant literature on sustainable lean in Indian context was done and a total of 40 CSFs representing individual dimensions of triple-bottom line were collected. A large number of factors have been identified to be the CSFs of sustainable lean for different types of manufacturing sector in the past years by many authors. Further, the collected factors which are considered to be the alternatives of the study are clustered into four major categories after discussions with the decision makers namely Management (M), Workforce (W), Operational (O) and Knowledge (K) factors. The alternatives under each category is listed in Table 1.

The hybrid multi-criteria decision making technique used in the study is explained in this section and is briefly presented in Fig. 1. The selected factors were then shortlisted using COPRAS method, based on the responses collected from the decision makers. A questionnaire relating each factor to the selected parameters depicting five different dimensions of sustainable lean was used to collect the response. The various CSFs were ranked on the basis of various parameters such as Stakeholders satisfaction, Environmental impact reduction, Productivity improvement, Cost for implementation and Technical difficulty in collecting data for the CSFs.

In the first phase of research, the qualitative analysis, we have conducted semi structured interviews with various stakeholders. To achieve the research objectives, a team of panel members from the case organization was formed. The team had 5 experts or decision makers (DM) from various departments of the case organization. Each panel member has a working expertise of over 7–10 years in their respective departments and also has a good knowledge about lean principles and significance. The details of the experts are shown in Table 2. We approached these decision makers for helping us to understand the CSF which are needed for SLM adoption in EECM industry. A detailed session was conducted to make them understand the research objectives. The session was followed by semi structured interview with each participant to collect insights on the problem faced by the company. The collected factors were discussed and finalized with the decision makers. The interviews were conducted on Zoom/MS teams/Skype.

The general aspects of Complex Proportional Assessment (COPRAS) are given as:

3.2. Shortlisting of CSFs using COPRAS method

The COPRAS is a multi-criteria decision making tool introduced by Zavadskas in 2008. This method involves identifying a set of testing parameters by the researcher. The available alternatives are then rated against the selected parameters with which the relative importance and utility level of the alternatives can be obtained (Ghorabaee et al., 2014; Govindan et al., 2019).

COPRAS method was used to identify the factors (or alternatives) with the highest utility degree in order to shortlist them. The COPRAS method was preferred in the study over the other approaches such as Delphi method, as it is more systematic and qualitative method. The Delphi method on the other had is quantitative where biasness of the decision makers is overlooked. COPRAs on the other hand is more mathematical and helps in systematic decision making. The parameters used for assessing, scale used for rating, procedure for data collection and results obtained are explained in the following subsections.

3.2.1. Determining the parameters and scale for rating

With the purpose of assessing the alternatives based on the triple bottom line and practical difficulty of the organization, three beneficial and two non-beneficial parameters were selected in such a way that each parameter represented a discrete aspect of sustainability. Subsequently a five-point likert scale ranging from very low (1) to very high (5) was selected for recording the numerical opinion of the DMs for the corresponding linguistic variable in order to rate the relationship of the alternatives with the selected parameters (Bai et al., 2019). The parameters and scale are shown in Table 3 and Table 4

Table 1
List of factors selected for study.

Category	Code	Factor	Description	Reference
Management	M1	Top-management commitment	Top-management commitment in adopting sustainable lean manufacturing	(Govindan et al., 2014), (Kumar et al., 2020)
	M2	Prioritize and select projects	Choose projects which has supports both sustainability dimensions and organization's strategic goals	(Kornfeld and Kara, 2013)
	M3	Make collaborative decisions	Organise brainstorming sittings at all levels of organization and make decision taking their inputs into account	Govindan et al. (2014)
	M4	Adopt Government regulations and standards	Integrate the standards and update the current regulations of government with the present operating procedure	(Luthra et al., 2018), (Malek and Desai, 2019)
	M5	Acquire cleanest technologies	Ready to acquire the technologies which have low impact on environment	(Toke and Kalpande, 2019)
	M6	Implement Green purchasing policy	Prefer purchasing products that has reduced impact on people and environment	(Toke and Kalpande, 2019), (Malek and Desai, 2019)
	M7	Upgrade to high quality manufacturing facilities	Enhance the production facility at right times in order to meet customer expectation and maximize efficiency	(Vinodh et al., 2011), (Kumar et al., 2020)
	M8	Readiness to invest	Maintain strong financial base and be prepared to invest for achieving organization's milestone	(Mani et al., 2015),(Prasad et al., 2018)
	M9	Engage in certification programs	Involve in 'certification programs which reinforce social and environmental sustainability in organization's operating procedure	(Mani et al., 2015), (Singh et al., 2016)
	M10	Establish company's brand image with sustainability dimension	Make efforts to project a socially responsible corporate image in society (Green company)	Gandhi et al. (2018)
	M11	Multi-skilled workforce	Maintain a workforce which can readily handle the updated	Kumar et al. (2020)

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Table 1 (*continued*)

Category	Code	Factor	Description	Reference
			facilities and dynamic tasks in production	
	M12	Focus on bench marking	For best practices focus in bench marking to gauge the performance of the firm to other organisations which lean implemented	(Tomelero et al., 2017), (da Costa et al., 2020)
	M13	Comply with legal requirements and auditing programs	Meet the legal environmental requirements by following the regulations of specific sector and conduct auditing programs which contributes to organisation's growth	Vinodh et al. (2015)
	M14	Measures to reduce environmental impact	Take accountability for environmental impact and deploy required effort to address and control the impact	(Chuang and Yang, 2014), (Luthra et al., 2018)
	M15	Organization's learning through HR development	Organization can utilize human resource development programs to mentor and assist the employees which in turn improves the performance of organization	(Kramar, 2014), (Macke and Genari, 2019)
Workforce	W1	Employee involvement	Involvement exhibited by the employees in adopting to working culture of sustainable lean	(Daily and Huang, 2001)
	W2	Rewards and recognition system	Maintain the practice of acknowledging the performance of employees with at most commitment	Mani et al. (2015)
	W3	Employee motivation	Enhancing workers efficiency through support and creating healthy workspace	Kumar et al. (2020)
	W4	Safety and ergonomics measures	Integrate human safety factors and ergonomics into working procedure to enhance quality and operational performance of employee	Sakthi Nagaraj et al. (2019)
	W5	Feedback from workforce	Receiving feedbacks about work culture and making employee feel empowered	(Kaswan and Rathi, 2019)
	W6			

Table 1 (*continued*)

Category	Code	Factor	Description	Reference
		Training programs	Providing awareness about recent technologies and updating employee skills and knowledge through proper training programs	Kumar et al. (2020)
Operational	O1	Effective scheduling	Eliminate the waiting time and improve productivity through effective scheduling	Vinodh et al. (2015)
	O2	Standardize the work	Determine the optimal sequence and process for the tasks to avoid confusion and complexity in workspace	Panizzolo et al. (2012)
	O3	Efficient use of information technology	Incorporate advanced communication system and information technology to eliminate time waste and barriers in information flow within organization	(Singh et al., 2016),(Luthra et al., 2018)
	O4	Control over defects	Bring down manufacturing lead time by predicting and scheduling maintenance of the equipment which causes defect in products	Vinodh et al. (2015)
	O5	Eco-friendly product design	Focus on developing products that avoid or reduce toxic or hazardous material use and maximise material utilization	Luthra et al. (2018)
	O6	Effective visual control	Utilize visual control to communicate the information about any process for quick recognition and clarity in understanding	(Motwani, 2003), (Panizzolo et al., 2012)
	O7	Cut down inventory	Reduce unnecessary inventory by employing proper forecasting technique and improve business performance	Gurumurthy et al. (2020)
	O8	Design reusable products	Design products which brings out maximum potential of materials through multiple life cycles and save resource utilization	(Habidin et al., 2018)

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Table 1 (*continued*)

Category	Code	Factor	Description	Reference
	O9	Adopt reduce, reuse, recycle	Employ design for manufacture and assembly which creates the scope for recycling and repairing of the product	(Habidin et al., 2018), (Vinodh et al., 2015)
	O10	Internal expertise	Make use of packaging materials, technology and disposal procedure which minimizes environmental impact and cut down cost	(Chuang and Yang, 2014)
	O11	Proper utilization of floor space	Build a reverse logistic network for proper handling of products at end of life-cycle and reduce material consumption which benefits the environment as well as business	(Toke and Kalpande, 2019)
Knowledge	K1	Run product life cycle assessment	Ensure availability of expert member inside the organization to track and direct while implementing sustainability principles	Govindan et al. (2014)
	K2	Link sustainable lean practices to business objectives	Workspace need to be properly organized to accommodate equipment and facilitate work by eliminating unproductive movements.	(Singh et al., 2014), (Toke and Kalpande, 2019)
	K3	Run product life cycle assessment	Conduct product life cycle assessment and attain knowledge about environmental impacts by the end of life-cycle	Cheung et al. (2017)
	K4	Link sustainable lean practices to business objectives	Reinforce sustainability aspect in every business related operation which includes innovation, customer engagement, supplier relationship, etc	(Govindan et al., 2014), (Kaswan and Rathi, 2019)
	K5	Source from environmentally friendly suppliers	Give priority to suppliers who incorporated and maintain an environmental management system with high standards	(Habidin et al., 2018)
	K6	Customer awareness	Make effort in creating awareness among the customers about eco-friendly products and their benefits over the other choices	Kumar et al. (2020)
	K7	Feedback from buyers	Involve buyers in quality program through feedbacks and learn from their response	Panizzolo et al. (2012)
	K8	Technical support to supplier	Provide technical support to the suppliers regarding issues in implementing sustainability concepts while collaborating	(Malviya and Kant, 2017)

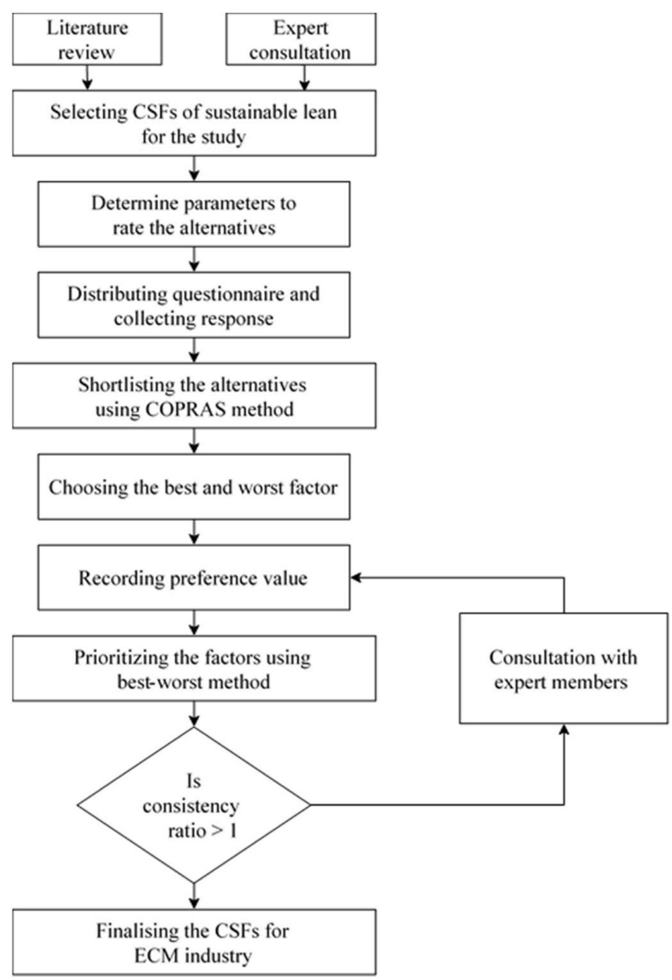

Fig. 1. Methodology.

3.2.2. Distributing questionnaire and response collection

A questionnaire based survey relating each parameter to individual alternative was designed. The questionnaire was initially distributed to few DMs who were asked to rate the strength of relation for each alternative with individual parameter. Pilot or a small scale investigation was done to assess the feasibility of the questionnaire. The data collected from the pilot study aided in modifying the final questionnaire

Table 2
Details of decision makers.

Sl.no	Job description
1	Product manager
2	Logistics associate
3	Maintenance engineer
4	Sales engineer
5	Marketing head

Table 3
Parameters for rating.

Sl. no	Parameter	Parameter code	Description
1	Stakeholders satisfaction	$P1^+$	The level of satisfaction for all the stakeholders from supplier to customer
2	Environmental impact reduction	$P2^+$	Contribution of the factor in bringing down negative environmental impact
3	Productivity improvement	$P3^+$	Enhance the output with minimum consumption of resources
4	Cost for implementation	$P4^-$	The cost incurred to the organization for implementing the factor
5	Technical difficulty	$P5^-$	Difficulty faced by the organization in technical aspect

Table 4
Five point likert scale.

Linguistic Variable	Numerical Value
Very low (VL)	1
Low (L)	2
Moderate (M)	3
High (H)	4
Very high (VH)	5

Table 5
Numbers and relative importance.

Number	Relative importance
1	Equally important
2	Weakly important
3	Moderately important
4	Moderately plus important
5	Strongly important
6	Strongly plus important
7	Very strongly important
8	Very, very strongly important
9	Extremely important

which was then distributed to the DMs for collection of their response. The final questionnaire form is included in Appendix 1.

3.2.3. *The procedure for COPRAS method*

Step 1 Initial decision matrix

Construct the initial decision matrix X from the numerical response of DMs by arranging the alternatives in rows (m) and the parameters in columns (n). Since there are five DMs, the five different decision matrices under each major criterion were aggregated into one by constructing aggregate decision matrix. By taking average of values by all DMs for each parameter, this can be constructed.

$$X = [Xij]_{mxn} = \frac{\sum_{d=1}^{5} xPi}{d}$$

where, i = {1, 2,.., 5}

Step 2 Normalized decision matrix

Normalized decision matrix (R) is formed by dividing the individual vale of a parameter to the sum of all values of that particular parameter.

Step 3 Weighted Normalized decision matrix

The weighted normalized decision matrix (D) is constructed by multiplying the normalized value of an alternative to the corresponding weight assigned to the parameter.

Step 4 Sum of Weighted Normalized Decision Matrix

The sum of beneficial values of an alternative (S_{+i}) and sum of non-beneficial values of an alternative (S-i) are calculated separately from the weighted normalized values as shown below,

$$S_{+i} = \sum_{j=1}^{n} y + ij$$

$$S_{-i} = \sum_{j=1}^{n} y - ij$$

Step 5 Relative significance of alternatives

The relative significance (Q_i) provides the importance of an alternative in relative to others. It is found using the following formula,

$$Q_i = S_{+i} + \frac{S - \min \sum_{i=1}^{m} S - i}{S - i \sum_{i=1}^{m} \left(\frac{S - min}{S - i}\right)}$$

Step 6 Calculate utility ratio

The utility ratio (U_i) provides the degree of profitability or usefulness of an alternative. The alternative with the highest percentage of utility is considered to be the best. The U_i is calculated using the formula shown below,

$$U_i = [\frac{Qi}{Qmax}]*100$$

The above mentioned procedure was used to shortlist the collected CSFs under each major criterion based on their utility value.

3.3. *Prioritizing the shortlisted CSFs using BWM*

The BWM is a multi-criteria decision making (MCDM) tool introduced by Jafar Rezaei in 2015. In this method, the best (most important) and the worst (least important) factors are selected by the decision maker from all the factors involved in the study. The selected factors are then compared pairwise with all the other factors by DM using range from 1 to 9, where 1 = "equally important" and 9 = "extremely important". Using these comparison values a minimization model is built and solved, which provides the weight of the factors and consistency ratio. Rezaei (2015) and Mi et al. (2019) found that BWM provides more consistent results eliminating the inconsistency in Analytical Hierarchy Process (AHP). This is because BWM requires less pairwise comparison than AHP. The major variation exists between the two methods is the mathematical function they involve. For BWM f(n) = 2n-3, whereas for AHP f(n) = n(n-1)/2. The standard procedure for BWM is explained below.

Step 1 Determine the decision factors

The factors which are going to be evaluated for finding the final decision are selected in this step.

Step 2 Select the best and worst factor

The best (most important) and the worst (least important) factors under each major criterion are selected by the decision maker.

Step 3 Determine the preference value for best to others

Determine the preference value by comparing the factor which is selected as the best with all the other factors in the particular criterion using a scale of 1–9. The best-to-others comparison will provide the following vector,

$F_B = (f_{B1}, f_{B2},.., f_{Bn})$

where f_{Bj} indicates the preference value provided for comparing the best factor B to the jth factor. When the best factor is compared to itself (f_{BB}), the preference value will be 1.

Step 4 Determine the preference value for others to worst

Determine the preference value by comparing all the factors of a criterion to the factor which is selected to be the worst using the 1–9 scale. The others-to-worst comparison will provide the following vector,

$F_W = (f_{W1}, f_{W2},.., f_{Wn})^T$

where f_{Wj} indicates the preference value provided for comparing the jth factor to the worst factor W. When the worst factor is compared to itself (f_{WW}), the preference value will be 1.

COPRAS methodology was adopted to understand the difficulty in evaluating the CSFs, once we are clear about the CSF for which data can be easily obtained, we start the prioritization process. Finally, the identified factors were evaluated and prioritized using BWM, from which the CSFs of SLM for the case organization were established. The procedure for performing the above mentioned hybrid methodology is explained in the following subsections. The BWM method uses two stage response collection process to understand the importance of each criteria. The detailed steps of the same are given below:

3.3.1. Two stage response collection

The response collection for BWM included two stages (see Table 5). In the first stage, the five DMs were asked to choose the best (most important) and the worst (least important) factor from all the criteria individually. This provided five different set of factors for each criterion. The questionnaire form used for collecting the best and the worst factors is given in Appendix 2. In the second stage, the DMs were asked to compare their selected factors to all other factors in that particular criterion by providing a preference value. The preference scale ranging from 1 to 9 was used for comparison as shown in Table 9. The comparison was made in the manner of weighing up the selected best factor to others and others to the selected worst factor. For the best to others comparison, preference value was provided in such a way that value for the best-best factor is ‘1’ and value for the best-worst value is ‘9’. The best to all other factors was awarded value between 1 and 9. Likewise for the others to worst comparison, preference value for the worst-worst factor is ‘1’ and value for the worst-best is ‘9’. All other factors to worst were awarded value between 1 and 9. Based on the response collected in the last step, best-to-others (BO) vector and others-to-worst (OW) vector were formed using the procedure explained in methodology. The questionnaire form used for recording comparison values and response collected are shown in Appendix 3.

3.3.2. Determine optimal weights

Find the optimal weight for each factor ($w_1^*, w_2^*,..,w_n^*$) in this step. The solution obtained is optimal when the weights for factors have $w_B/w_j = f_{Bj}$ and $w_j/w_w = f_{jw}$.

In order to meet these conditions for all the factors, the maximum absolute differences, $\left| \frac{wB}{wj} - f_{Bj} \right|$ and $\left| \frac{wj}{ww} - f_{jw} \right|$ for every factor are minimized. Taking the non-negativity condition and sum condition for weights into account, the following equation is attained,

$$\min_j \max\{|\frac{wB}{wj} - f_{Bj}|, |\frac{wj}{ww} - f_{jw}|$$

subject to,

$$\sum_j wj = 1$$

$w_j \geq 0$, for all j.

Then, a linear programming minimization model is generated from the above equation,

min ε

subject to,

$$|\frac{wB}{wj} - f_{Bj}| \leq \varepsilon \; for \; all \; j$$

$$|\frac{wj}{ww} - f_{iW}| \leq \varepsilon \; for \; all \; j$$

$$\sum_j wj = 1$$

$w_j \geq 0$, for all j.

The optimal weights ($w_1^*, w_2^*,..,w_n^*$) and optimal value ε* are obtained by solving the above problem for all the DMs.

Table 6
Utility degree for management factors.

Code	P1+	P2+	P3+	P4-	P5-	S+i	S-i	Qi	Ui
M1	0.01811	0.016176	0.017692	0.011765	0.010924	0.051979	0.022689	0.083066	100
M2	0.012598	0.013971	0.012308	0.011765	0.013445	0.038877	0.02521	0.066855	80.48422
M3	0.014173	0.010294	0.013846	0.01098	0.013445	0.038313	0.024426	0.06719	80.88774
M4	0.014173	0.013971	0.013077	0.013333	0.013445	0.041221	0.026779	0.06756	81.33309
M5	0.013386	0.013971	0.013077	0.011765	0.012605	0.040433	0.02437	0.069377	83.51964
M6	0.012598	0.014706	0.010769	0.014902	0.014286	0.038074	0.029188	0.062239	74.92723
M7	0.015748	0.013235	0.016154	0.015686	0.015126	0.045137	0.030812	0.068029	81.89689
M8	0.012598	0.013971	0.013846	0.013333	0.010924	0.040415	0.024258	0.069492	83.65871
M9	0.011024	0.013971	0.012308	0.014118	0.012605	0.037302	0.026723	0.063697	76.68184
M10	0.011811	0.009559	0.009231	0.014902	0.010924	0.030601	0.025826	0.057912	69.71729
M11	0.013386	0.011765	0.016154	0.014118	0.014286	0.041304	0.028403	0.066137	79.62004
M12	0.012598	0.0125	0.014615	0.013333	0.013445	0.039714	0.026779	0.066053	79.51896
M13	0.011024	0.016176	0.012308	0.013333	0.014286	0.039508	0.027619	0.065046	78.30615
M14	0.013386	0.014706	0.01	0.014902	0.016807	0.038092	0.031709	0.060336	72.63613
M15	0.013386	0.011029	0.014615	0.011765	0.013445	0.039031	0.02521	0.067009	80.66952

Table 7
Utility degree for workforce factors.

Code	P1+	P2+	P3+	P4-	P5-	S+i	S-i	Qi	Ui
W1	0.031148	0.04	0.031667	0.028571	0.028571	0.102814	0.057143	0.179808	100
W2	0.034426	0.032941	0.033333	0.037363	0.030952	0.100701	0.068315	0.165103	91.82185
W3	0.032787	0.030588	0.031667	0.030769	0.035714	0.095042	0.066484	0.161219	89.66134
W4	0.036066	0.030588	0.035	0.037363	0.038095	0.101654	0.075458	0.15996	88.96142
W5	0.034426	0.028235	0.03	0.028571	0.030952	0.092662	0.059524	0.166576	92.6408
W6	0.031148	0.037647	0.038333	0.037363	0.035714	0.107128	0.073077	0.167334	93.06235

Table 8
Utility degree for operational factors.

Code	P1+	P2+	P3+	P4-	P5-	S+i	S-i	Qi	Ui
O1	0.016575	0.01704	0.02246	0.016346	0.017172	0.056075	0.033518	0.095359	96.81775
O2	0.020994	0.017937	0.02246	0.017308	0.018182	0.061392	0.03549	0.098493	100
O3	0.018785	0.018834	0.02139	0.020192	0.019192	0.059009	0.039384	0.092442	93.85583
O4	0.01768	0.017937	0.023529	0.016346	0.017172	0.059146	0.033518	0.09843	99.93609
O5	0.016575	0.019731	0.012834	0.017308	0.019192	0.04914	0.0365	0.085215	86.51827
O6	0.018785	0.015247	0.018182	0.017308	0.017172	0.052213	0.034479	0.090402	91.78453
O7	0.016575	0.015247	0.019251	0.016346	0.017172	0.051073	0.033518	0.090357	91.73895
O8	0.016575	0.018834	0.013904	0.019231	0.019192	0.049312	0.038423	0.083582	84.86037
O9	0.016575	0.018834	0.016043	0.019231	0.017172	0.051451	0.036402	0.087623	88.96305
O10	0.01768	0.019731	0.012834	0.020192	0.020202	0.050245	0.040394	0.082841	84.10868
O11	0.023204	0.020628	0.017112	0.020192	0.018182	0.060945	0.038374	0.095257	96.71447

Table 9
Utility degree for knowledge factors.

Code	P1+	P2+	P3+	P4-	P5-	S+i	S-i	Qi	Ui
K1	0.025	0.024638	0.029457	0.025954	0.022951	0.079095	0.048905	0.130064	100
K2	0.025	0.023188	0.029457	0.024427	0.027869	0.077646	0.052296	0.125309	96.34449
K3	0.023529	0.026087	0.027907	0.025954	0.022951	0.077523	0.048905	0.128492	98.79159
K4	0.022059	0.021739	0.031008	0.022901	0.027869	0.074806	0.05077	0.123903	95.2629
K5	0.023529	0.030435	0.021705	0.027481	0.02459	0.07567	0.052071	0.123539	94.98364
K6	0.025	0.026087	0.017054	0.030534	0.022951	0.068141	0.053485	0.114745	88.22233
K7	0.027941	0.021739	0.021705	0.019847	0.02459	0.071386	0.044437	0.127479	98.01239
K8	0.027941	0.026087	0.021705	0.022901	0.02623	0.075734	0.04913	0.126469	97.23584

Then, using the consistency index and optimal value ε*, consistency ratio for each DM is calculated. The consistency ratio always ranges from 0 to 1. The closer the value of ratio to 0, indicates the comparison is more consistent.

Consistency ratio = ε* / consistency index.

The implementation of the above discussed methodology in the case organization is explained in the next section.

4. Data analysis

The case organization, selection of factors, shortlisting and prioritizing the CSFs for EECM using the hybrid methodology are presented in this section.

4.1. Result obtained using COPRAS method

The responses for 15 management factors, 6 workforce factors, 11 operational factors and 8 knowledge factors from five DMs were organized separately and steps of COPRAS were performed. After discussion with DMs, equal weights were applied to each parameter for determining weighted normalized matrix. The result for management factors is shown in Table 6 in which weighted normalized matrix, relative significance and utility degree are presented.

It can be observed from the table that the factor which holds the highest utility degree come by 100% and the utility degree for remaining factors descends gradually. It can also be noted that the factors having high value in beneficial parameters and low value in non-beneficial parameters will be holding the top utility degrees. This is because of the fact that those factors favour the organization in sustainability dimensions and have less difficulty in implication. In management criterion, 'top management commitment' (M1) got the highest utility (100%) and 'establish company's brand image with sustainability dimension' (M10) got the lowest utility (69.71%). Although 'upgrade to high quality manufacturing facilities' (M7) got next highest value for stakeholders satisfaction ($P1^+$) and productivity improvement ($P3^+$), it obtained fourth Ui because of high cost ($P4^-$) and technical difficulty ($P5^-$) for the implementing organization. For shortlisting purpose, the factors which

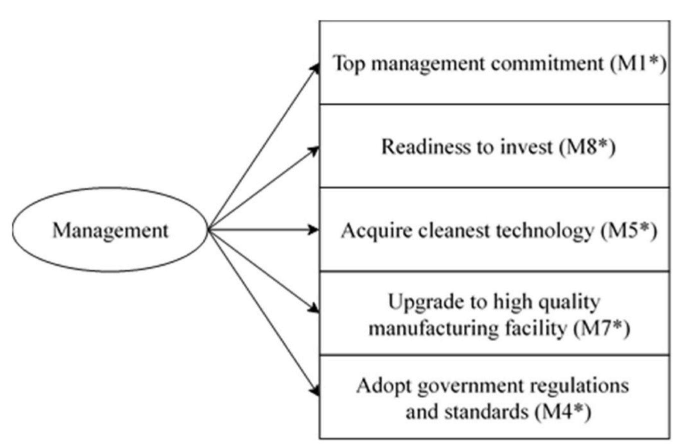

Fig. 2. Shortlisted factors for management criteria.

secured top five utility degree values were selected from every criterion. The management criterion with five shortlisted factors, as shown in Fig. 2, is then used in BWM.

The same procedure is followed to shortlist the workforce, operational and knowledge factors. Regarding workforce criterion, 'employee involvement' (W1) got the highest utility (100%) and 'safety and ergonomics measures' W4 got the lowest utility (88.96%) as shown in Table 7. Here, even though safety and ergonomics are very important and got the highest $P1^{+}$ of all the factors, the high values in $P4^{-}$ and $P5^{-}$ (non-beneficial parameters) have resulted in lower degree of utility. The five shortlisted factors of workforce criterion are shown in Fig. 3.

Coming to operational criterion, 'standardize the work' (O2) secured the highest utility degree (100%) and 'environment friendly packaging' (O10) secured the lowest utility degree (84.10%) as shown in Table 8. Environment friendly packaging got the lowest position in this criterion because of its less contribution to beneficial aspects when compared to high non-beneficial demands. 'Eco-friendly product design' got high value in $P2^{+}$ and less rating for $P1^{+}$ and $P3^{+}$ which brought sum of beneficial parameters closer to sum of non-beneficial parameters resulting in low utility degree. The operational criterion with five shortlisted factors is presented in Fig. 4.

Regarding knowledge criterion, 'internal expertise' (K1) secured the top utility degree (100%) and 'customer awareness' (K6) got the lowest utility degree (88.22%) as given in Table 9. 'Customer awareness' towards sustainable products is an important factor, however the less contribution by the factor to productivity ($P3^{+}$) of the organization with high cost for implementing ($P4^{-}$) has resulted in low utility for the factor. Likewise 'link sustainable lean practices to business objectives' (K4) and 'sourcing from environmentally friendly suppliers' (K5) got comparatively less values due to the difficulty involved in implementation with moderate benefits gained for organization. The knowledge criteria with five shortlisted factors is presented in Fig. 5.

All the above mentioned 20 factors are further evaluated with BWM in the next section.

4.2. Evaluating the factors using best-worst method

In this section, BWM was used to evaluate and prioritize the shortlisted factors to determine the final CSFs for the electronic component manufacturing organization involved in the study.

Following the formation of priority vectors from the collected preference values, the optimal weights for the factors are found. For this purpose, a linear programming minimization model was used to generate separate priority vector for each DM as explained in the procedure. The optimal weights and consistency ratio are then determined by solving the model. Since responses from five DMs were used, each 20 factors under four criteria would get five different weights corresponding to them. For the sake of finding the final weight of a factor, weighted mean is calculated from all the optimal weights obtained. Also while calculating weighted mean, equal significance to each decision maker's opinion was ensured by providing equal weightage individually. The final weights obtained for all the factors under four different criteria are presented in Table 10 and the finalized CSF are given in Table 11.

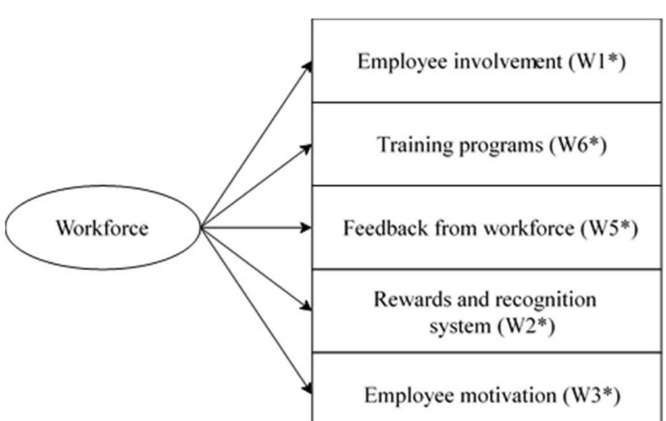

Fig. 3. Shortlisted factors for workforce criteria.

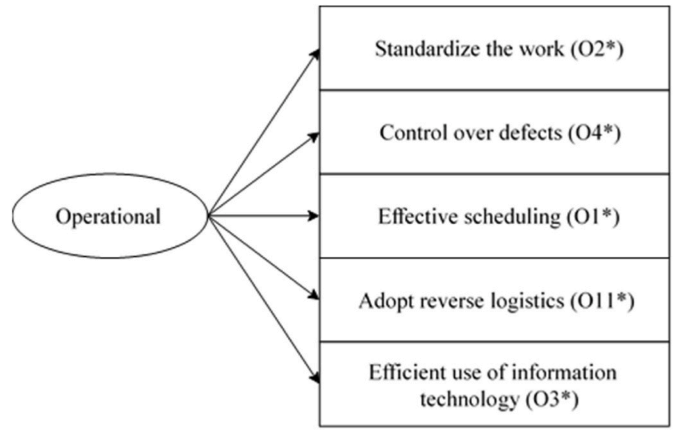

Fig. 4. Shortlisted factors for operational criteria.

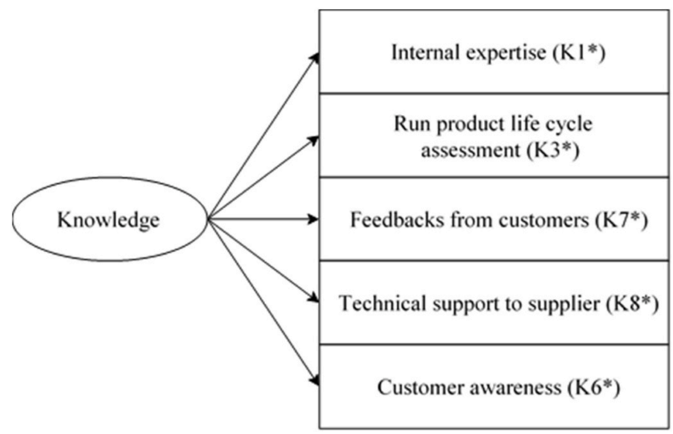

Fig. 5. Shortlisted factors for knowledge criteria.

Based on the final weight obtained, the factors are ranked from 1 to 5. Under management criterion, 'top management commitment (M1*)' got first place by holding highest weight (0.0779) of all management factors followed by 'readiness to invest (M8*)' which got second rank with next highest weight (0.0541) implying the significance of financial support from the organization. 'Acquire cleanest technologies (M5*)' secured third highest weightage (0.0399) indicating the importance of controlling environmental impact through management's contribution. 'Adopt government regulations and standards (M4*)' got fourth weightage (0.0159) signifying the demand on the management in adopting standards. 'Upgrade to high quality manufacturing facilities

Table 10
Final weights for the factors.

Management	Workforce	Operational	Knowledge
code/final wgt	code/final wgt	code/final wgt	code/final wgt
(M1*)0.0779	(W1*)0.0698	(O2*)0.0692	(K1*)0.0734
(M8*)0.0544	(W6*)0.0543	(O4*)0.0672	(K3*)0.063
(M5*)0.0399	(W5*)0.051	(O1*)0.0141	(K7*)0.0368
(M7*)0.0117	(W2*)0.0137	(O11*)0.0281	(K8*)0.0154
(M4*)0.0159	(W3*)0.011	(O3*)0.0212	(K3*)0.0112

Table 11
Finalised CSFs from the study.

Rank	Code	Factors
1	M1*	Top-management commitment
2	K1*	Internal expertise
3	W1*	Employee involvement
4	O2*	Standardize the work
5	O4*	Control over defects
6	K3*	Run product life cycle assessment
7	M8*	Readiness to invest
8	W6*	Training programs
9	W5*	Feedback from workforce
10	M5*	Acquire cleanest technologies
11	K7*	Feedback from buyers
12	O11*	Adopt reverse logistics
13	O3*	Efficient use of information technology
14	M4*	Adopt Government regulations and standards
15	K8*	Technical support to supplier

(M7*)' got the fifth weight, ranking last in the management criterion (0.0117). The consistency ratio of the optimal weights for management factors derived from five DMs are as follows: DM1 = 0.0986, DM2 = 0.0859, DM3 = 0.0746, DM4 = 0.0950, DM5 = 0.0707.

Analysing the weights of workforce factors, 'employee involvement (W1*)' got first rank with the highest weightage (0.0698) establishing the significance of workforce readiness in sustainable lean implementation. 'Training programs (W6*)' came second with next weightage (0.0543) which stresses the skill development of the workers. It was followed by 'feedback from workforce (W5*)' which was ranked third (0.0510) underscoring the importance of considering employee opinion for healthy work environment. Fourth rank was acquired by 'rewards and recognition system (W2*)' with weight (0.0137) indicating the value for recognising employee effort in business environment. And, 'employee motivation (W3*)'secured fifth position with least weightage (0.0110) showing the level of importance for motivated employee. The consistency ratio of the optimal weights for workforce factors derived from five DMs are as follows: DM1 = 0.0746, DM2 = 0.0927, DM3 = 0.0499, DM4 = 0.0761, DM5 = 0.0549.

Regarding operational factors, 'standardize the work (O2*)' secured the first position with highest weight (0.0692) highlighting the prominence of building and maintaining a standard operating procedure. The second highest weight (0.0672) was acquired by 'control over defects (O4*)' exhibiting the importance of preventing defects before occurring with appropriate techniques. 'Adopt reverse logistics (O11*)' got the third position (0.0281) indicating the significance of setting up the network to collect the used and extinct products and 'efficient use of information technology (O3*)' was given fourth rank (0.0212) stressing the need for expeditious information flow in the organization. Finally, 'effective scheduling (O1*)' ranked last (0.0141) conveying the necessity for eliminating time waste in the operations. The consistency ratio of the optimal weights for operational factors derived from five DMs are as follows: DM1 = 0.0711, DM2 = 0.0976, DM3 = 0.0986, DM4 = 0.0781, DM5 = 0.0711.

Likewise for knowledge factors, 'internal expertise (K1*)' acquired the first rank with highest weightage (0.0734) which exhibits the demand for having an expert for sustainable lean principles inside organization. 'Run product life cycle assessment (K3*)' secured the second rank (0.0630) intimating the need to acquire knowledge about all the stages of a product life cycle followed by 'feedbacks from customers (K7*)' at third rank (0.0368) underlying the importance of assessing and knowing the performance from consumer point of view. The fourth rank (0.0154) was acquired by 'technical support to supplier for green activities (K8*)' conveying the significance of extending the organization's sustainable principles to the stakeholders. And, 'proper utilization of floor space (K2*)' ranked fifth (0.0112) indicating the level of importance for having the knowledge to design a proper workspace eliminating unproductive activities. The consistency ratio of the optimal weights for knowledge factors derived from five DMs are as follows: DM1 = 0.0709, DM2 = 0.0847, DM3 = 0.0973, DM4 = 0.0586, DM5 = 0.0859.

5. Discussion

Advanced smart devices are being innovated, produced and consumed all over the globe persistently. Irrespective of the discipline, electronics is impinging into every technological device and becoming an inevitable ingredient in innovations which are considered to be the future. In order to bring such exceeding devices in real time, the demand for various types of electrical components is sky high. To meet demands of this kind with excellent quality, the electronics component manufacturing industry is gearing up with full enthusiasm. Growing pressure from stakeholders to reduce waste is the main reason academia is focusing on the analysis of sustainable lean factors in manufacturing industries. Lean manufacturing aims in reducing costs by eliminating wastes and non-value-added activities, which is the focal point for all top management (Shokri et al., 2021). SLM aims to improve efficiency by freeing up employees and resources for innovation and quality control that would have previously been wasted. Thus, the focus of academia has integrated this mechanism as a business modelling approach that needs immediate attention.

A total of 40 success factors were collected from the available literature on sustainability and lean concepts and finalized for the study after discussions with the panel members from the case organization. The panel had five decision makers from different departments of the organization. The collected factors were then classified into four criteria and shortlisted using COPRAS method based on the responses collected from the decision makers. The factors with top five utility degrees were shortlisted from each criterion which contracted 40 into 20 factors. The shortlisted 20 factors were further evaluated and prioritized using BWM. Optimal weights for the factors were found based on the responses from five decision makers. From the optimal weights calculated using BWM, weighted mean was determined to find the final weights. Ranking was provided to the 20 factors depending on the final weights obtained. The factors which got top 15 ranks were finalized to be the CSFs for the case organization in implementing sustainable lean principles. The Top-management commitment (M1*) has the highest priority in the sustainable lean CSF. The willingness from the management in implementing SLM was ranked to be the most important factor, since every business and strategic decision is taken by the people at administration level. Involvement of top-management was found to have direct impact on working culture and competitive advantage of the organization over the competitors. The Top-management commitment gained the highest priority in the sustainable lean CSF, since every business and strategic decision is taken by the people at administration level. Involvement of top-management was found to have direct impact on working culture and competitive advantage of the organization over the competitors. Focus from the management is essential as they drive the whole process of leading and implementing SLM in industries. The recent pandemic has also questioned the survivability of many EECM industries problems, with low investment, the sustainability and resilience of the sector is at stake. Less waste and better adaptability makes for a business that's better equipped to thrive well into the future. Further, the study by Wijethilake and Lama (2019) supports the claim that top management commitment has positive effect on the sustainability practices of the companies. Another essential CSF is the Internal expertise (K1*), the availability of experts in SLM principles inside the organization to direct and monitor the process got second most importance. This is because many organizations lack in attaining the expected improvement in performance even after adopting lean and sustainability concepts due to absence of proper guidance when any problem is detected (Vinodh et al., 2015). Also absence of technical expertise was identified to be a barrier in SLM implementation (Govindan et al., 2014).

According to the results Employee involvement (W1*) got third rank which stresses the significance of human factors required while implementing a new normal. Fulfilling the technical and scientific aspects alone won't help the organization in achieving sustainability when the human factors and involvement are left unsatisfied (Daily and Huang, 2001). Academia must focus on identifying the ways to engage workforce to adapt lean sustainable manufacturing to reduce wastage and sustain in long run. Standardization of the operations can overcome the existing mismatch between available technology and employee skills. Employees should be trained not only on lean principles, but on the specific lean methods and processes to be utilized moving forward. The paper by Kumar et al. (2019) supports this CSF by stating that the employee involvement and creativity is a crucial environment problem-solving resources for adapting lean in processes. Standardizing the work got the fourth importance out of 15 top factors. Work standardization has a direct role in enhancing productivity of the organization as it removes the unwanted complexity in performing the operations. In addition, a standardized workspace will have least possibility of accidents with improved safety level (Gandhi et al., 2018). The study by Jakhar et al. (2018) aligns with this CSF, it states that the standardization of the work leads to reduction in the waste, thereby promoting the lean sustainable production Another essential CSF is the Control over defects (O4*), which further reduce the wastage of the resources. Producing a defective product or service is vain for both organization and consumer. Incorporating scheduled maintenance as an element in organization's conventional operation will eliminate such defects even before occurring. This can be achieved by analysing the operations involved in production cycle and finding the source of defects which makes it possible to deliver the products to the buyer at the scheduled time without any delay (Vinodh et al., 2015). The control of imperfect quality items is directly related to the monetary benefits (Jakhar et al., 2018). This is followed by run product life cycle assessment (K3*). Conducting product life cycle assessment is important in the electrical component manufacturing industry as production of the surge protector and earthing system involves usage of metal oxide nanoparticles which could be a threat to environment. The knowledge about impact caused in the stage of production, usage and end of life can be studied in detailed using LCA technique which in turn helps the organization while manufacturing such products (Cheung et al., 2017). The paper by Blass and Corbett (2018) asses the life cycle environmental impact used at the supply chain and firm levels to be more resilient and sustainable.

The readiness to invest (M8*) by the Management's inclination for adoption of sustainable lean principles got seventh rank. The level of financial support from organization will have a major influence in adopting sustainability principles successfully, since every technique of sustainability which includes up gradation of facility, knowledge and decision making comes with a cost (Mani et al., 2015; Prasad et al., 2018). A strong training programs (W6*) of the firm helps in enhancing the lean and sustainable practices. All the strategies and scientific techniques are executed in real time of production by the employees. To make any manufacturing philosophy work on the production floor, upgrading the employee skills and knowledge is an inevitable factor. India is one of the countries which have seen downward trend in skill adequacy in recent years. Scale up reskilling and up-skilling in emerging skills, combined with active labour market policies is established to be one of the priorities of human factor development. Acquiring feedback about the working culture (W5*) is another crucial CSF, which enhances the employee empowerment, which in turn motivates them. Providing a healthy working environment to the employees is essential for achieving the organization's business goals. Considering employees' opinion and making required alternations were set to improve commitment level of employees (Daily and Huang, 2001). India should amend labour laws and social protection for the new economy and the new needs of the workforce. The paper by Agarwal et al. (2021), cites the need for the industries to upskill and reskill the employees to gain competitive sustainable advantage and reduce wastage.

Acquire cleanest technologies (M5*) is an important CSF which aims in reducing the ecological impact and enhancing the leanness of the firm. Readiness to acquire the cleanest technology was an important factor for achieving long-term sustainability goals. With the right technology which is having less pessimistic impact to the planet, the environmental aspect of sustainability can be attained (Toke and Kalpande, 2019). The Feedback from buyers (K7*) aims in the overall satisfaction of customers, which is the ultimate goal for any organization which drives the need for development programs. Involving buyers in quality program through feedback effectively helps the organization to realize where to focus. Feedback from the consumers or collaborating organizations will reveal not only the quality of the product from client's point of view, but also the expectations, perceptions and trends of the market (Panizzolo et al., 2012).

Adopting a reverse logistic network (O11*) to support proper handling of products at the end of life-cycle which will reduce new material consumption. This will benefit the environment as well as the business. This is because manufacturing of electronic components involves usage of materials which need proper and safe way of disposal of waste or reusing them. Adopting this principle will help the development of organization and the society (Toke and Kalpande, 2019). Efficient use of information technology (O3*) helps the organizations in incorporating an advanced communication system to eliminate the barriers in information flow both internally and externally. Efficient use of information technology eliminates the unpredictability associated with a network of supplier and buyer by enhancing the information flow timely (Singh et al., 2016; Luthra et al., 2018).

Adopt government regulations and standards (M4*): Adopt the recent regulations of government and take part in international certification programs which focus on standards for social and environmental welfare like ISO 14001, ISO 9001 and ISO 26000. It supports sustainable performance of the organization with getting a good brand image (Mani et al., 2015). Technical support to supplier (K8*) regarding issues in implementing sustainability concepts while collaborating. The suppliers who are smaller business firms compared to the large-scale organization will have a support and also will be demanded to follow sustainable lean principles benefiting the triple bottom line. But, on the contrary a reduction in collaboration between companies was observed due to the pandemic which needs to be focussed and eliminated immediately. Hence, the above discussed 15 factors are crucial CSFs for the case electrical component manufacturing industry in implementing the sustainable lean manufacturing.

6. Conclusions

Increasing global awareness about sustainability in the field of EECM sector for a clean and safe living environment demands reforming the conventional production techniques to attain a heightened level of triple-bottom line performance (WEF, 2020). So, achieving the business goals along with environment prevention and embracing social factors can be supported by incorporating sustainable lean practices, which is the motivation behind the current paper. The implementation of sustainable lean practices is pressuring the industrial leaders to understand the factors for becoming lean and sustainable in their manufacturing operations. The primary requirement for Indian EECM sector is to identify the CSF that can be adopted in their production and operations systems.

Concerning to the discussed issues, this study involved in identifying and prioritizing the CSF for implementing SLM concepts in one of the EECM organizations. Although many researchers have already established the CSFs for SLM, the fuzziness associated with factors selection for the study through discussion with experts remains obscured. The literature lacks the analytical evaluation of the CSF in the view of exploring their significance level before modelling or prioritizing them. A team of five experts from various departments of the case organization were identified, having a working expertise of over 7–10 years in their respective departments. A hybrid multi-criteria decision making technique was employed in the present study. In the first step of the study involved collecting the critical success factors for SLM from the available literature and analysing them with the help of decision makers. A total of 40 CSFs representing Management (M), Workforce (W), Operational (O) and Knowledge (K) factors were collected. The selected factors were then shortlisted using COPRAS method, based on the responses collected from the decision makers. COPAS was used to shortlist the CSF based on the ease of collecting information. In the second step BWM multi-criteria decision making technique was employed and 20 CSFs were finalized for implementing sustainable lean. BWM was used to evaluate and prioritize the shortlisted factors to determine the final CSFs for the electronic component manufacturing organization involved in the study.

The results found from the methodology established top-management commitment in implementing SLM, availability of an internal expert who can monitor and provide proper guidance to the organization and involvement level of employees in accepting, learning and practicing new principles to be the top three CSFs for the case organization. Focus from the management is essential as they drive the whole process of leading and implementing SLM in industries. The identified factors will help the people at the managerial level of EECM industry to make right decisions which in turn will benefit the triple bottom line. The recent pandemic has also questioned the survivability of many EECM industries problems, with low investment, the sustainability and resilience of the sector is at stake.

The future studies may consider extending the research by involving more industries as respondents which will make the outcomes generic. The COPRASs and BWM method utilises expert opinion which are difficult to gather. Moreover, these methods are mathematical in nature so data collection is a tedious process. The biasness of the sample size and the respondents are also limitation of the study. The shortlisted factors can be mathematically modelled with advanced analytical tools in order to provide a framework for SLM implementation in EECM industries. In addition to that, in a country with varying geography and cultures like India, it is quite hard for the findings from one particular region of a country to work out in other regions. A practical case implementation is needed when the results found are to be incorporated countrywide, to include this aspect more industries and decision makers can be interviewed. Future studies may also benefit from other emerging approaches to incorporate hybrid approaches. This study can also be extended to other areas and disciplines.

CRediT authorship contribution statement

K. Mathiyazhagan: Conceptualization, Writing – review & editing, Supervision. **A. Gnanavelbabu:** Writing – review & editing, Supervision. **Naveen Kumar.N:** Writing – original draft. **Vernika Agarwal:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1. Questionnaire form for rating the factors

FACTORS	RESPONDENT DETAILS				
	$P1^+$	$P2^+$	$P3^+$	$P4^-$	$P5^-$
Management	(VL = 1, L = 2, M = 3, H = 4, VH = 5)				
M1	…				
M2	…				
M3	…				
.	…				
.	…				
.	…				
.	…				
.	…				
External	…				
E3					
E4					

Appendix 2. Questionnaire form for selecting best and worst factor

	CRITERIA				
	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
BEST					
WORST					

Appendix 3. Questionnaire form for recording comparison values

The most important factor	Other factors
The least important factor	
Other factors	

(*continued on next page*)

(*continued*)

The least important factor

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