Journal of Scientific & Industrial Research
Vol. 79, August 2020, pp. 720-726

Assessment and Implementation of Lean and Green Supply Chain in Medium Scale Automobile Industries using AHP and Fuzzy TOPSIS

S N Sathiya Narayana[1], P Parthiban[2]*, Anbuchezhian[3] and R Dhanalakshmi[4]

[1]Department of Mechanical Engineering, Jayaram College of Engineering and Technology, Tiruchirappalli 620 015, India
[2]Department of Production Engineering, National Institute of Technology, Tiruchirappalli 620 015, India
[3]Department of Mechanical Engineering, RMD Engineering college, Kavaraipettai 600 077, India
[4]Department of Computer Science and Engineering, Indian Institute of Information Technology Tiruchirappalli, Trichy 620 015, India,

Received 4 February 2019; revised 21 March 2019; accepted 21 May 2020

For several years manufacturing industry has been flourishing in India and among the manufacturing industries automobile is one of the fundamental. This paper focuses on the execution of the lean and green supply chain in the medium scale automobile industrial sectors. The critical factors are discovered dependent on expert's opinion and through questionnaires sent to the industries. The significance and the degrees of the factors are taken from interpretive structural modeling. Utilizing these levels, the critical weights of each factor are obtained through analytic hierarchy process (AHP). The critical weights are used in TOPSIS and Fuzzy TOPSIS, to find out the efficiency of the industries.

Keywords: AHP, Fuzzy TOPSIS, Manufacturing industry, Structural modeling

Introduction

Supply Chain Management

The flow of goods and services management which involves all processes which transform raw materials into end products is called Supply Chain Management. Supply chain management operations include the procurement of raw materials, inventory control, warehousing, and transportation of end-use goods from production to point of consumption. Supply Chain Management strategies help the organization achieve a strategic edge in the marketplace. Some of the goals include integrated performance, streamlined logistics, reduced time, minimized work in progress, reduced transport costs, reduced warehousing costs, improved quality, and long-term stability, etc. Supply chain management consists of eight elements. They are goods, plan, data, source, inventory, output, site, shipping, and return. Customer requirements, globalization, competition, government policy, climate, and information technology are the factors influencing supply chain management.

Lean Supply Chain Management

Lean supply chain management is a community of companies directly connected by the flow of goods, resources, information, and funds that work to minimize waste and expense by efficiently pulling out what is needed to meet consumer needs. It's not for the businesses that make products but for the trade that wants to upgrade their processes by removing waste. Lean supply chain management's operational advantages include lead time or decreased cycle time, increased efficiency, reduced inventory of work-in-process, improved quality, and lower use of space. For lean supply chain management, the 5S involves sorting, putting for order, standardizing, maintaining. The 3R in handling the lean supply chain includes reducing, reusing, and recycling. Waste disposal can be achieved in several different ways. Some of them include reducing the production of pre-produced goods, reducing inline waiting for products, reducing unnecessary movement of products from various locations during manufacturing and distribution, reducing unnecessary processing of products, reducing the amount of inventory held, minimizing the defects requiring the rework, reducing the number of products transported.

Green Supply Chain Management

Integrating sustainable thinking into supply chain, which involves design of the product, procurement, and the selection of material, production processes final goods distribution and even end-life management of the product after its useful life. The

*Author for Correspondence
E-mail: parthee_p@yahoo.com

organizations must focus to make the goods safe and make it competitive. End consumers want more environmentally friendly goods and this creates a connection between environmental factors and revenue. There are several ways companies can cut costs by minimizing the commodities' environmental impact. For the supply chain activity, which involves buying planning and materials management, a complete reconsideration is required. Supply chain executives need to be prepared to develop the logistics system that goes along with the corporations' green policies. Reducing waste disposal spending happens in the supply chain cycle often reduces system spending. By embracing the management of the green supply chain we have financial benefits, communal benefits, and green benefits. Some financial benefits include increased returns, cost minimization, better customer service, etc. Some social benefits include fitness, hygiene, safety, reducing noise, etc. Several environmental benefits include reduced waste, increased energy efficiency, decreased air and water emissions, fuel consumption, etc.

Multi-Criteria Decision Making (MCDM)

The multi-criteria decision making (MCDM) techniques are built-in capability to judge different alternatives on a variety of criteria for feasible choice of the best options. These alternatives can be more inspected in detail for their final employment. The MCDM study has a few unique characteristics like the occurrence of many non-consumable and antagonistic criteria, various units of measurement along with the criteria, and the presence of quite many alternatives. The MCDM techniques involve analytic hierarchy process (AHP), data envelopment analysis (DEA), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), VIKOR and Decision-Making Trial and Evaluation Laboratory (DEMATEL).

Small and medium-sized enterprises (SMEs) play a major role in developed and developing countries alike. Emerging countries such as India work in a very competitive world for SMEs. The SMEs were the backbone of the Indian economy and have a prominent place in the well-developed economy.[1] Nevertheless, it could be difficult for SMEs to manage with the increase in scientific innovation due to inadequate resources and the short of finances available to them. Through technological development towards industry 4.0, where the majority of manual operations are preloaded through automated systems and robots, and produced creations are smart goods with rooted systems; SMEs are not able to compete positively to supply consumers with attractive goods.[2] Lean and green initiatives each include management engagement and participation of staff, recognition and elimination of organizational waste and continuous organizational progress.[3] Companies ought to consistently attempt to concentrate on waste minimization that happens in the whole creation process. Types of enhancement for the creation line with the use of lean manufacturing technique are utilized to distinguish waste along the worth stream and to discover non esteem included exercises. Lean manufacturing itself has its shortcomings and qualities, as expressed in past exploration, the investigation expressed that SMEs have various attributes for lean manufacturing.[4] A close relationship between a supplier and a consumer increases the accuracy of demand information and the sensitivity of the consumer, which decreases the production preparation time which obsolescence of the inventory. Conversely, a close relationship between a producer and a supplier facilitates the manufacturing cycle of material distribution, which in turn helps manufacturers produce goods on time.[5] Taherdoost *et al*.[6] sums up the way toward directing analytical hierarchy process (AHP). The AHP is one of the most comprehensive framework which is considered to settle on choices with different models since this strategy define the issue at various levels and accept a blend of quantitative and subjective measures also. Minimizing waste and reducing the usage of natural resources is a major aim of green sustainability, and is directly connected to Lean's objective of waste removal. In terms of the information produced by the literature of Lean and Green Supply Chain, the degree of relatedness is even greater. Green practices are just those activities carried out inside the supply chain to eradicate or minimize any adverse effect on the environment without compromising quality, efficiency and operating costs.[7]

Sartal *et al*.[8] analyse environmental and information technologies (ET & IT) in the capacity of lean manufacturing (LM) to accomplish improved modern execution. In their examination, they tried speculations in a multi-sectoral test of 763 processing plants among 5 European nations. They found that LM rehearses activated IT & ET execution due to serious necessities and innovation empowered capacities. Just in Time is the well known inventory model and a typical lean rule that is utilized in the supply chain to ensure that it is given to deliver the

perfect measure of items at the opportune time and fulfill quality necessities.[9] Operations research and design of experiments (DOE) procedures can be applied in lean standards to distinguish most impacting factors and get an ideal structure of assembling forms.[10]

Toyota motors applied lean manufacturing in their production system.[11] Lean manufacturing techniques have proven to be positively effective in most of the manufacturing fields. Launching and introducing lean production and the effects of this change on the organization, and capturing and assessing differences in approach.[12] Six-Sigma was introduced in 1986 by Smith and Harry while working at Motorola, and in 1995 by General Electric. This is focused on enhancing process performance, finding and eliminating the causes of faults, and reducing process variability.[13] Additionally, there is clear evidence that the concurrent functioning of lean practices focused internally and externally produces greater performance advantages than selective lean production. Knowing the dynamics is important and the advantages that affect sustainable manufacturing initiatives. Not all barriers have the same degree of impact on the sustainable supply chain. Those barriers therefore need to be rated. Such hurdles can be measured, and the MCDM software can list them.[14]

Experimental Details

Problem Definition

Hijaz *et al*.[15] says the medium-scale automobile industries are concentrating mostly on lean factors without considering the impact on the surroundings because of these factors. This can show the lack of awareness given to green foundation and ecological pressure, where there's no eagerness to implement green procedure in most of the businesses. Because of the raised government policies and rules, and also the developed public knowledge in environmental safety, companies currently simply cannot ignore environmental issues if they need to carry on in the worldwide market.[16] Therefore, when applying green on the supply chain we are going to succeed lean and green execution. The main idea is to calculate the successfulness of the execution of lean and green techniques in the medium-scale automobile production sectors.

Factors Affecting the Implementation of Lean and Green Supply Chain

A literature review was conducted on the factors that affect the execution of lean and green practices in a supply chain of the automobile industry. The factors are:

***Purpose of the Organisation (P)*:** Basically, the main purpose of the organization should be inclined both in lean and in green ways so that the implementation would be achieved. Green creation requires long term move toward as ecological impacts lead by enterprises had been for several years.[17] Elevated thinking growth leads to better purpose of the organization which in turn guides to increasing the level of lean and green execution.

***Structure of the Organisation (S)*:** The structure of the organization as in the management, leadership, nature of the employee relationships with their superiors and the similar. This aspect is very important because achieving lean and green in the supply chain of a particular industry would be difficult without good management and without the right decision making at the right time.

***Design of product and process (D)*:** The way the end result and the processes involved in the manufacturing and designs are very important for achieving lean and green. Designing the product or the process is the part of the supply chain.

***Customer Satisfaction (CS)*:** If the customer is satisfied in accordance to the final end product then the lean ways would be achieved. Sometimes the customer would also expect the product to be environmentally safe.

***Logistics (L)*:** Logistics is a very important part in lean and green. As we know the types of waste transportation, different motions involved are part of lean wastes. Therefore, it is better to reduce the usage of logistics and go according to the lean ways. As in the green supply chain, the less the movement or transportation and shipping, the less will be the carbon dioxide or other harmful gases release due to the usage of fuels leading to less harm to the environment.

***Supplier relationships (SR)*:** The relationship with the supplier is very important and also selecting the right supplier is very important, because sometimes there might be time constraints and the raw materials or the outsourced parts should be delivered on time else the product would be delivered late. And also, the cost of raw materials may also vary according to the relationship with the suppliers.

***Environmental performance (E)*:** The overall environmental performance of the organisation would encourage the companies to adopt lean and green

supply chain. Sometimes the environmental performance might be a trade-off for the lean principles when applied and also the green implementation when applied, automatically the environmental performance will increase.

***Capacity of the Organisation (CO)*:** Capacity of the organisation would include financial capacity, production capacity, human resource capacity, information capacity etc. If the capacity is more it is easier to achieve lean and green manufacturing.

***Willingness to change (W)*:** Willingness to change is most important factor to change the natural battle in human beings.[17] Greater willingness to change would lead to more lean and green execution.

***Recycling (R)*:** The product which would be returned by customers should be made it reuse. In this factor it also means about the ability of the organisation towards the inclination of recycling. Recycling will dropping ecological loads as it is most essential waste reducing system.[18]

***Government support (G)*:** The implementation of lean and green requires huge financial support. So by providing advantages like tax relaxation, subsidies on green actions would encourage the organisation to incline towards lean and green. The main difficulty of green execution is the lack of government support.[19]

***Quality (Q)*:** The quality of the product delivered and other aspects of quality which are followed in the process of the manufacturing and quality aspects in the services provided come under this factor. The quality would affect the customer satisfaction. The identification of waste and also the environmental aspects affects the quality.

Ananlytic Hierarchy Process (AHP)

Analytic hierarchy process is a planned method based on psychology and mathematics to organize and analyze the complex decisions. AHP helps the decision makers determine the one that most suits their aim and their understanding of the problem. Steps in AHP are as given below:

Step 1 — Calculation of Comparison matrix (A)

In comparison matrix, we rank the criteria corresponding to each other on a scale of 1–9. The n × n real matrix is a matrix A, where n is the number of evaluation criteria considered. In matrix A all the entries of a_{ij} denote the i_{th} criterion dominant; it is interrelated to j_{th} criterion. If criterion j_{th} is fewer important than the i_{th} if $a_{ij} > 1$ then the criterion j_{th} is highly important than i_{th} if $a_{ij} < 1$. If both criteria are equally dominating if $a_{ij} = 1$. The entries a_{ij} and a_{ji} satisfy the following constraint:

$a_{ij} \times a_{ji} = 1$ and $a_{ii} = 1$ for all i

Ranking scale of criteria:

Value of a_{ij} Interpretation is shown in Table 1.

Step 2 — Normalization of comparison matrix

The normalized pairwise comparison matrix A ($\bar{A}$) is calculated by adding the entries on each column equal to 1,

Step 3 — Finding the priority vector (X) or Criteria weights

We get the priority matrix (X) by taking the row averages of normalized matrix A (bar).

Step 4 — Finding the eigenvalue (λmax)

Step 5 — Calculation of consistency ratio (CR)

We calculate the consistency ratio (CR) to find how consistent the judgments have been relative to large samples of purely random judgments. If the consistency ratio (CR) is greater than 1, the judgments are unworthy, and if consistency ratio (CR) is less than 1, the judgments are worthy, and we can proceed to next step.

The ratio of consistency index (CI) to random index (RI) is known as consistency ratio random Index (RI) is obtained from a random index table. The value changes with the change in criteria.

Step 6 — Determining the priority vector for alternatives based on the criteria

We find the comparison matrix between the alternatives based on each criterion. After obtaining the comparison matrix, we normalize the matrix to get the priority vector by taking row averages. This priority vector contains the weights of each alternative for each criterion.

Step 7 — Ranking the alternatives based on criteria or finding Score matrix(S)

We get the ranking by multiplying the alternative priority matrix and criteria weights. Alternative priority matrix is determined from the priority vectors of alternatives based on each criterion. By multiplying alternative priority matrix and criteria weights, score matrix is obtained. Arrangement of the scores in

Table 1 — The fundamental ranking scale

1	i and j are equally important
3	i is moderately important than j
5	i is strongly important than j
7	i is very strongly important than j
9	i is extremely important than j
2, 4, 6, 8	used to express intermediate values

ascending order gives the ranks or the order of priority of the alternatives. The comparison matrix and normalization comparison matrix are shown in Table 2 & Table 3.

From the above comparison matrix and weights, the eigen values are found. From this eigen value, we calculate the consistency index followed by consistency ratio by taking random index from table. We get λ_{max} = 12.027 and consistency index as 0.002453. The consistency ratio is 0.0015929. As the consistency ratio is less than 0.1(CR < 0.1) the judgments are worthy. Random Index from the Table 2 is taken as 1.54.

Fuzzy TOPSIS

Hwang and Yoon suggested the TOPSIS[20] and it is a popular method for resolving MCDM issues. This method is an idea from the selected alternative will have closest distance to positive ideal solution (PIS) (the solution can reduce price and increase the gain criteria's) and longest distance to negative ideal solutions (NIS). Chen introduced the extensive technique for TOPSIS is vertex method.[21] It is used for evaluating the distance between two triangular FNs. If $\overline{x}$ = (a1, b1, c1), $\overline{y}$ = (a2, b2, c2) are two triangular FNs. The procedure of fuzzy TOPSIS as follows:

Step 1 — Assign a rating to criteria and alternatives

We made the assumption that we have a decision group with' K ' members. The fuzzy rating of the k^{th} decision maker about alternative A_i w.r.t. criterion C_i signifies $x_{ij}^{k} = \left(a_{ij}^{k}, b_{ij}^{k}, c_{ij}^{k}\right)$ and the weight of criteria C_j signifies $w_j^{k} = \left(w_{j1}^{k}, w_{j2}^{k}, w_{j3}^{k}\right)$.

Step 2 — Calculate the aggregated fuzzy ratings for alternatives and the aggregated fuzzy weights for criteria

The aggregated fuzzy rating $\overline{x_{ij}} = (a_{ij}, b_{ij}, c_{ij})$ of the i^{th} alternative w.r.t the obtained j^{th} criterion.

The aggregate fuzzy weight $\overline{w_j} = (w_{j1}, w_{j2}, w_{j3})$

Step 3 — Calculate the normalized fuzzy decision matrix(NFDM)

The NFDM is $\overline{R} = [\overline{r}_{ij}]$.

Table 2 — Comparison matrix

	P	S	D	CS	L	SR	E	CO	W	R	G	Q
P	1	1	3	3	3	3	3	0.333	1	3	0.2	3
S	1	1	3	3	3	3	3	0.333	1	3	0.2	3
D	0.333	0.333	1	1	1	1	1	0.2	0.333	1	0.143	1
CS	0.333	0.333	1	1	1	1	1	0.2	0.333	1	0.143	1
L	0.333	0.333	1	1	1	1	1	0.2	0.333	1	0.143	1
SR	0.333	0.333	1	1	1	1	1	0.2	0.333	1	0.143	1
E	0.333	0.333	1	1	1	1	1	0.2	0.333	1	0.143	1
CO	3	3	5	5	5	5	5	1	3	5	0.333	5
W	1	1	3	3	3	3	3	0.333	1	3	0.2	3
R	0.333	0.333	1	1	1	1	1	0.2	0.333	1	0.143	1
G	5	5	7	7	7	7	7	3	5	7	1	7
Q	0.333	0.333	1	1	1	1	1	0.2	0.333	1	0.143	1
	13.33	13.33	28	28	28	28	28	6.4	13.33	28	2.933	28

Table 3 — Normalised comparison matrix

	P	S	D	CS	L	SR	E	CO	W	R	G	Q	SUM	SUM/12
P	0.075	0.075	1071	1071	1071	1071	1071	0.0521	.0.075	0.1071	0.0682	0.1071	1.0953	0.0913
S	0.075	0.075	1071	1071	1071	1071	1071	0.0521	.0.075	0.1071	0.0682	0.1071	1.0953	0.0913
D	0.025	0.025	0.0357	0.0357	0.0357	0.0357	0.0357	0.0313	0.025	0.0357	0.0487	0.0357	0.405	0.0337
CS	0.025	0.025	0.0357	0.0357	0.0357	0.0357	0.0357	0.0313	0.025	0.0357	0.0487	0.0357	0.4049	0.0337
L	0.025	0.025	0.0357	0.0357	0.0357	0.0357	0.0357	0.0313	0.025	0.0357	0.0487	0.0357	0.4049	0.0337
SR	0.025	0.025	0.0357	0.0357	0.0357	0.0357	0.0357	0.0313	0.025	0.0357	0.0487	0.0357	0.4049	0.0337
E	0.025	0.025	0.0357	0.0357	0.0357	0.0357	0.0357	0.0313	0.025	0.0357	0.0487	0.0357	0.4049	0.0337
CO	0.225	0.225	0.1786	0.1786	0.1785	0.1786	0.1786	0.1563	0.225	0.1786	0.1136	0.1786	2.1949	0.1829
W	0.075	0.075	0.1071	0.1071	0.1071	0.1071	0.1071	0.0521	.0.075	0.1071	0.0682	0.1071	1.0953	0.0913
R	0.025	0.025	0.0357	0.0357	0.0357	0.0357	0.0357	0.0313	0.025	0.0357	0.0487	0.0357	0.4049	0.0337
G	0.375	0.375	0.25	0.25	0.25	0.25	0.25	0.4688	0.375	0.25	0.3409	0.25	3.6847	0.3071
Q	0.025	0.025	0.0357	0.0357	0.0357	0.0357	0.0357	0.0313	0.025	0.0357	0.0487	0.0357	0.4049	0.0337

Step 4 — Calculate the weighted normalized fuzzy decision matrix(WNFDM)

The WNFDM is $\bar{\bar{V}} = (\bar{v_{ij}})$, where $\bar{v}_{ij} = \bar{r}_{ij} \times w_j$.

Step 5 — Calculate the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS)

Step 6 — Calculate all the alternative distance to the FPIS and FNIS

Step 7 — Evaluate the closeness coefficient CC_i

We calculate the closeness coefficient CC_i for all alternatives Ai.

Step 8 — Rank the Alternatives

The high value closeness coefficient alternative can represent the best one. The first step in fuzzy TOPSIS is to devise the decision matrix, and here we get a matrix of the dimensions 10*36 as we have twelve factors and we have to write the fuzzy set each of the factors, and we also have ten industries to rank. Next is to allow weights for every factor in the fuzzy set, here the criteria already have a set highest and lowest value of one and five the fuzzy set is devised accordingly. In this case, we have divided the weight each criterion into three equal parts for the lowest, most possible, highest scores. After the weights are assigned, we have mention whether it is cost or profit criteria by mentioning min and max for cost and profit respectively. Then the Fuzzy MCDM packages are loaded to carry on the fuzzy TOPSIS calculations to get the ranking of the industries as a result.

Results and Discussion

Initially the comparison matrix and Normalized comparison matrix is calculated. From which the eigen value is obtained as λ_{max} =12.027. Then consistency index and consistency ratio are obtained as 0.002453 and 0.0015929 respectively by using eigen value. The results of critical weights of the factor which are obtained from AHP are presented in Table 4 and Table 5.

The R studio software is used to run the codes. The results obtained from the software are presented in Table 5, which presents that the industry which has the maximum R-value, the combined distance of the alternative from Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS), is the best in implementing Lean and Green practices in their supply chain.

Table 4 — Critical factors

Factors	Value
Purpose of organisation(P)	0.09
Structure of organisation(S)	0.09
Design of product and process(D)	0.03
Customer satisfaction (CS)	0.03
Logistics(L)	0.03
Supply relationships (SR)	0.03
Environmental performance(E)	0.03
Capacity of organisation (CO)	0.2
Willing to admit change(W)	0.09
Recycling(R)	0.03
Government support(G)	0.32
Quality(Q)	0.03

Table 5 — Fuzzy TOPSIS Ranking

Alternatives	R	Ranking
1	0.01844030	7
2	0.01858414	5
3	0.01779174	10
4	0.01780082	9
5	0.01949293	2
6	0.01883352	4
7	0.01966114	1
8	0.01909803	3
9	0.01809855	8
10	0.01850356	6

Conclusions

The questionnaire was prepared to evaluate the performance of medium scale Indian automobile manufacturing industries regarding lean and green implementation and to know the extent to which lean and green concept has been applied to these industries. This paper had depicted the twelve factors for execution of lean and green framework in medium scale automobile manufacturing industries in India. Among the acquired results we found out the factors which affect the implementation of the lean and green supply chain in the medium scale automobile manufacturing industries. Essential weights are obtaining using AHP. Using these weights, the industries can be ranked, or the performance is measured using Fuzzy TOPSIS. After this, further the improvements can be made in the industry according to their performance and the performance can be found out again. Thus, results obtained from AHP shows that the factor *government support* and *the capacity of organization* are found to be very important and critical for implementing lean and green concept.

References

1 Jaiswal P & Kumar A, Analyzing barriers of lean manufacturing adoption in Indian SMEs using an integrated approach of grey decision making trial and evaluation laboratory (DEMATEL), *Proc of the Wor Cong on Engg*, London *2*, 2016, 688–691.

2 Qin J, Liu Y & Grosvenor R, A Categorical Framework of Manufacturing for Industry 4.0 and Beyond, *Procedia CIRP*, **52** (2016) 173–178.

3 Bergmiller G G & McCright P R, Are lean and green programs synergistic, *Proc of the 2009 Indus Engg Res Conf*, 2009, 1155–1160.

4 Moeuf A, Tamayo S, Lamouri S, Pellerin R & Lelievre A, Strengths and weaknesses of small and medium sized enterprises regarding the implementation of lean manufacturing, *IFAC-Papers On Line*, **49** (2015) 71–76.

5 Huo B, Gu M & Wang Z, Green or lean? A supply chain approach to sustainable performance, *J Clean Prod*, **216** (2019) 152–166.

6 Taherdoost H, Decision making using the analytic hierarchy process (AHP); A step by step approach, *Int J Econ Manag Syst*, **2** (2017) 244–246.

7 Campos L M S & Vazquez-Brust D A, Lean and green synergies in supply chain management, *Supply Chain Manag*, **21** (2016) 627–641.

8 Sartal A, Llachb J, Vázquez X H & de Castro, How much does Lean Manufacturing need environmental and information technologies, *J Manuf Syst*, **45** (2017) 260–272.

9 Wang S & Ye B, A Comparison Between Just-in-time and Economic Order Quantity Models with Carbon Emissions, *J Clean Prod*, **187** (2018) 662–671.

10 Durakovic B, Design of Experiments Application, Concepts, Examples: State of the Art, *Period Eng Nat Sci*, **5** (2017) 421–439.

11 Aziz R F and Hafez S M, Applying lean thinking in construction and performance improvement, *Alex Eng J*, **52** (2013) 679–695.

12 Salonitis K & Tsinopoulos C, Drivers and barriers of lean implementation in the Greek manufacturing sector, *Procedia CIRP*, **57** (2016) 189 – 194.

13 Mancosu P, Nicolini G, Goretti G, De Rose D, Franceschini F, Ferrari D C, Reggiori G, Tomatis S & Scorsetti M, Applying Lean-Six-Sigma Methodology in radiotherapy: Lessons learned by the breast daily repositioning case, *Radiother Oncol* 127(2) (2018) 326–331.

14 Hofer C, Eroglu C & Hofer A R, The effect of lean production on financial performance: The mediating role of inventory leanness, *Int J Prod Econ*, **138** (2012) 242–253.

15 Hijaz S, Al-Hujran O, Al-Debei M M & Abu-Khajil N, Green supply chain management and SMEs: a qualitative study, *Int J Bus Inf Syst*, **18(2)** (2015) 198–220.

16 Regattieri A, Mora C & Botti L, Application of a mathematical model for ergonomics in lean manufacturing, http://dx.doi.org/10.1016/j.dib.2017.06.050.

17 Ottar B, Govaert T & Landeghem H V, Challenges and success factors for implementation of lean manufacturing in European SMES, *Proc 13th International conference on the modern information technology in the innovation processes of the industrial enterprise (MITIP 2011)*, Vol. 1, Tapir Academic Press, 2011.

18 Bergmiller, Gary G., and Paul R. McCright. "Are lean and green programs synergistic." In *Proceedings of theIndustrial Engineering Research Conference*, 2009, pp. 1155–1160.

19 Parthiban P & Abdul Zubar H, An integrated multi-objective decision making process for the performance evaluation of the vendors, *Int J Prod Res* **51(13)** (2013) 3836–3848.

20 Chithambaranathan P, Subramanian N, Gunasekaran A & Palaniappan P K, Service supply chain environmental performance evaluation using grey based hybrid MCDM approach, *Int J Prod Econ*, **166** (2015) 163–176.

21 Kathirvel P, Parthiban P & Amaladhasan S, Studies on sustainable supply chain barriers of suppliers to the thermal power heavy industry, *J Sci Ind Res*, **78** (2019) 368–372.