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Identifying and Ranking Critical Success Factors for Implementing Leagile Manufacturing Industries Using Modified TOPSIS

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Abstract**—**Leagile is combination of both lean and agile system. Lean is concerned with less of everything i.e. less material, less time, less space, less manpower to produce a product, while agile is concerned with quick respond to customer demand and to reconfigure the system as soon as possible to meet the customer expectations well on time. The market is excessively competitive, so there is a dire need for the companies to adopt new and modern technologies with latest equipments. It has been seen that implementation of leagile system become tedious so the purpose of the paper is to find critical success factors (CSF) affecting leagile manufacturing system using literature review and rank them by using modified TOPSIS (Technique of order preference by similarity to ideal solution) technique.

Keywords**—**Agile manufacturing, lean manufacturing, leagile manufacturing, modified TOPSIS.

I. Introduction & Literature review

LEAGILE manufacturing system is found to have many advantages in the manufacturing system. Various researchers have described the leagile model. Reference [5] proposed a leagile model where lean and agile system operates by positioning de-coupling point at different points in a manufacturing supply chain. The de-coupling point separates lean and agile system; upstream lean system is followed while downstream agile system is adopted. Reference [2] also discussed the importance of de-coupling point. Reference [24] also discussed the importance of de-coupling point. Reference [3] pointed out that lean and agile paradigm has become the necessity for the success of any supply chain in twenty first century. Therefore, integration of both the strategies led to the development of the leagile principles. Reference [12] was the first one to introduce the concept of leagility. Leagile system helps in reducing the excess inventories and losses that can be there when the demand changes.

In recent years there is a drastic change in the competition. To tackle with competitive in the market, companies are required to use advanced manufacturing technologies and smart strategies such as computer integrated manufacturing (CIM), flexible manufacturing system, poka yoke, TQM (Total Quality Management), just in time, quality management system, rapid manufacturing, rapid prototyping, six sigma, lean and agile manufacturing, business process reengineering and business excellence models, which have claimed to support organization's improvement efforts. References [26] and [9] developed an operational model which can be used to assess changes required to introduce lean manufacturing. Reference [15] also explains some guidelines about applicability of lean practices in industry.

The structure of the paper contains is as follows: Section II contains the CSF affecting leagile manufacturing system which has been identified through literature review. Section III contains questionnaire conducted by industry experts, Section IV contains the procedure of modified TOPSIS technique. Section V contains the calculations of different critical factors and ranking them. Section VI contains discussion and conclusion.

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II. Identifications of CSF Affecting Leagile Manufacturing System

Various factors affecting leagile manufacturing system have been identified through literature review. These are listed in Table I.

TABLE I
CSF Affecting Leagile Manufacturing System

S.NO	Critical Success Factor (CSF'S)	References
1	Virtual Enterprises	[3], [4], [10],[20],[28]
2	Management support towards implementation of policies	[8], [13],[14],[17]
3	Strategic Management	[1], [4]
4	Knowledge and IT management	[2], [5]
5	Customer and Market sensitiveness	[6], [13], [25]
6	Rapid Reconfiguration	[7], [9], [11]
7	Design and Engineering	[15], [21]
8	Use of advance manufacturing technologies	[16], [22],[31]
9	Flexible manufacturing system	[13], [19], [25]
10	Supply chain Management	[5], [13]
11	Availability of funds	[21], [27], [4]
12	Training and development programs	[23], [26], [7]
13	Collaborative relationship	[24], [8], [7]
14	Benchmarking	[13], [19]
15	Human Resource management	[12], [18], [25]

III. Questionnaire Based Survey

A. Instrument Development

Based on literature review and discussion with experts and academicians, questionnaire was prepared. It contains CSF's which were necessary for leagile implementation in enterprises.

B. Survey Responses and the Respondents' Profile

The questionnaire was send to 60 companies. The companies selected are auto-mobile ancillary companies. 35 responses were received. 5 of them were partially completed and hence discarded. So, only 30 of companies were selected for data analysis. The response rate was 50%. Out of 30, 15 have employees less than 100, 7 have employees between 101 and 250, 5 have employees between 251 and 300 and 3 have employees between 301 and 400. In terms of turnover, 10 have turnover up to $10 million, 5 have turnover ranging $10-20 million, 10 in the range of $20–100 million, 5 in the range of $100–200 million.

C. Result of Survey

The main purpose of the questionnaire based survey was to find the crisp or fuzzy scores of the identified CSF. Major result of the survey was that 50% of the companies were interested in implementing leagile manufacturing system. The experts have given crisp values of different factors.

IV. Modified TOPSIS Technique

Table I shows critical success factors affecting leagile manufacturing system, identified through literature review. The experts were asked to fill the questionnaire by assigning fuzzy or crisp values as shown in Table II. 0.045 stands for exceptionally low while 0.955 stands for exceptionally high.

The first step is to determine the objective. The second step represents a matrix based on all the information available on factors. Each row of the matrix is allocated by onefactor and each column is assigned value by expert. In the case of a subjective attribute (i.e., objective value is notavailable), a ranked value judgement is adopted [30]. Reference [22] proposed an approach for solving more than ten alternatives in the system, linguistic term are convetred into fuzzy numbers and then fuzz ynumbers are converted into crisp scores. An 11-point scale is used in this paper for crisp score, as shown in Table II.

TABLE II
CONVERSION OF LINGUISTIC TERMS INTO FUZZY SCORES (11 POINT SCALE)

Linguistic Term	Fuzzy Number	Crisp No.
Exceptionally Low	M1	0.045
Extremely low	M2	0.135
Very low	M3	0.255
Low	M4	0.335
Below average	M5	0.410
Average	M6	0.500
Above average	M7	0.59
High	M8	0.665
Very High	M9	0.745
Extremely high	M10	0.865
Exceptionally high	M11	0.955

The third step is to obtain the positive ideal solution (best) and negative ideal solution (worst). The ideal (best) and negative ideal (worst) solutions can be expressed as:

$$R^{+}=\left\{\left(\sum_{1}^{Max}R_{ij}\,/\,j\in J\right),\left(\left(\sum_{1}^{Min}R_{ij}\,/\,j\in J'\right)/\,i=1,2..N\right)\right\}$$
$$=\left\{R_{1}^{+},R_{2}^{+},R_{3}^{+}\ldots\ldots.R_{M}^{+}\right\} \tag{1}$$

$$R^{-}=\left\{\left(\sum_{1}^{Max}R_{ij}\,/\,j\in J\right),\left(\left(\sum_{1}^{Min}R_{ij}\,/\,j\in J'\right)/\,i=1,2..N\right)\right\}$$
$$=\left\{R_{1}^{-},R_{2}^{-},R_{3}^{-}\ldots\ldots.R_{M}^{-}\right\} \tag{2}$$

The fourth step is to decide on the relative importance (i.e., weights) of different attributes with respect to the objective. A set of weights, wj (for j = 1, 2,……,M) such that Σwj= 1 may be decided upon. The weights of relative importance of the criteria may be assigned using the analytic hierarchy process (AHP) method [2].

The relative normalized weight (wj) of each attribute is calculated by following steps:

- calculating the geometric mean of ith row
- normalizing the geometric means of rows in the comparison

This can be represented as

$$GM_{j}\left(\sum_{i}^{M}b_{ij}\right)^{1/m} \quad \text{and} \quad W_{J}=GM_{j}\Big/\sum_{j=0}^{M}GM_{j}$$

The geometric mean method of AHP is commonly used to determine the relative normalized weights of the attributes, because of its simplicity, ease,determination of the maximum Eigenvalue, and reduction in inconsistencyof judgments.[29]

- Calculate matrices $A3$ and $A4$ such that $A3 = A1 * A2$ and $A4 = A3 / A2$ where $A1$ is the pair wise factor and $A2$ is weight of factors [8]
- Determine the maximum eigenvalue λmax that is the average of the matrix $A4$. Calculate the consistency index $CI = (\lambda\max - M)/(M-1)$ The smaller the value of CI, the smaller is the deviation from the consistency.
- Obtain the random index (RI) for the number of attributes used in decisionmaking [22].
- Calculate the consistency ratio $CR = CI / RI$. Usually, a CR of 0.1 or less isconsidered as acceptable, and it reflects an informed judgmentattribute to the knowledge of the analyst regarding the problem under study[30]

In fifth step, weighted Euclidean distances are calculated as:

$$D_{i}^{+}=\left\{\sum_{j=1}^{M}W_{j}\left(R_{ij}-R_{j}^{+}\right)^{2}\right\}^{1/2}\ where\ i=1,2,3,.................N \tag{3}$$

$$D_i^- = \left\{ \sum_{j=1}^{M} W_j \left(R_{ij} - R_j^- \right)^2 \right\}^{1/2} \quad where\ i = 1, 2, 3, ...N \quad (4)$$

In sixth step, the relative closeness of a particular alternative to the ideal solution, *Pi*–mod, can be expressed as:

$$P_{i\,\mathrm{mod}} = D_i^- / \left(D_i^+ + D_i^- \right) \quad (5)$$

In seventh step, a set of alternatives is made in the descending order, according to the value of *Pi*–mod indicating the most preferred and least preferred feasible solutions. *Pi*–mod may also be called the overall or composite performance score of Factor Fi.

V. Calculations Involved

In first stage, fuzzy or crisp values of the factors affecting leagile manufacturing system are tabulated as given by experts, Table III.

In second stage, Normalized Decision matrix is calculated by (6) and it is shown in Table IV.

$$N_{ij} = m_{ij} / \left(\sum_{j=1}^{m} m_{ij}^{\ 2} \right)^{1/2} \quad (6)$$

TABLE III
FUZZY OR CRISP VALUE OF FACTORS

	Experts														
CSF	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
F1	0.41	0.41	0.865	0.335	0.335	0.255	0.335	0.665	0.59	0.255	0.5	0.59	0.5	0.41	0.59
F2	0.865	0.665	0.59	0.5	0.5	0.59	0.5	0.745	0.335	0.865	0.59	0.41	0.5	0.59	0.41
F3	0.745	0.59	0.5	0.5	0.59	0.59	0.5	0.5	0.41	0.745	0.41	0.5	0.41	0.41	0.5
F4	0.135	0.665	0.5	0.335	0.41	0.5	0.41	0.5	0.5	0.5	0.59	0.5	0.59	0.5	0.5
F5	0.41	0.5	0.665	0.41	0.5	0.59	0.5	0.665	0.59	0.59	0.5	0.59	0.335	0.5	0.255
F6	0.335	0.335	0.41	0.5	0.5	0.41	0.745	0.59	0.59	0.59	0.5	0.59	0.745	0.665	0.59
F7	0.335	0.255	0.335	0.5	0.5	0.335	0.59	0.59	0.41	0.41	0.5	0.255	0.335	0.335	0.5
F8	0.41	0.335	0.665	0.665	0.5	0.865	0.665	0.41	0.745	0.59	0.41	0.41	0.41	0.59	0.59
F9	0.665	0.135	0.59	0.255	0.5	0.59	0.5	0.5	0.865	0.5	0.59	0.255	0.59	0.41	0.135
F10	0.5	0.5	0.5	0.5	0.335	0.5	0.59	0.255	0.5	0.5	0.745	0.335	0.59	0.5	0.255
F11	0.5	0.5	0.255	0.59	0.135	0.5	0.665	0.41	0.59	0.335	0.665	0.745	0.745	0.135	0.41
F12	0.5	0.59	0.665	0.59	0.255	0.665	0.745	0.41	0.59	0.255	0.255	0.5	0.335	0.5	0.59
F13	0.59	0.665	0.665	0.255	0.5	0.5	0.59	0.5	0.41	0.665	0.5	0.5	0.255	0.5	0.5
F14	0.335	0.59	0.5	0.5	0.335	0.5	0.5	0.59	0.335	0.745	0.5	0.255	0.5	0.255	0.5
F15	0.5	0.59	0.59	0.335	0.41	0.255	0.59	0.335	0.335	0.255	0.41	0.5	0.5	0.5	0.41

TABLE IV
NORMALIZED MATRIX

	Experts														
CSF's	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
F1	0.2062	0.2064	0.3905	0.1852	0.1983	0.1238	0.1511	0.3258	0.2818	0.1193	0.2466	0.3157	0.2534	0.2244	0.325
F2	0.4351	0.3348	0.2664	0.2764	0.296	0.2864	0.2255	0.365	0.16	0.4046	0.291	0.2194	0.2534	0.3229	0.2259
F3	0.3747	0.2971	0.2257	0.2764	0.3492	0.2864	0.2255	0.245	0.1958	0.3485	0.2022	0.2675	0.2078	0.2244	0.2755
F4	0.0679	0.3348	0.2257	0.1852	0.2427	0.2427	0.1849	0.245	0.2388	0.2339	0.291	0.2675	0.2991	0.2737	0.2755
F5	0.2062	0.2517	0.3002	0.2266	0.296	0.2864	0.2255	0.3258	0.2818	0.276	0.2466	0.3157	0.1698	0.2737	0.1405
F6	0.1685	0.1687	0.1851	0.2764	0.296	0.199	0.336	0.2891	0.2818	0.276	0.2466	0.3157	0.3776	0.364	0.325
F7	0.1685	0.1284	0.1512	0.2764	0.296	0.1626	0.2661	0.2891	0.1958	0.1918	0.2466	0.1364	0.1698	0.1834	0.2755
F8	0.2062	0.1687	0.3002	0.3676	0.296	0.4199	0.2999	0.2009	0.3558	0.276	0.2022	0.2194	0.2078	0.3229	0.325
F9	0.3345	0.068	0.2664	0.1409	0.296	0.2864	0.2255	0.245	0.4131	0.2339	0.291	0.1364	0.2991	0.2244	0.0744
F10	0.2515	0.2517	0.2257	0.2764	0.1983	0.2427	0.2661	0.1249	0.2388	0.2339	0.3674	0.1792	0.2991	0.2737	0.1405
F11	0.2515	0.2517	0.1151	0.3261	0.0799	0.2427	0.2999	0.2009	0.2818	0.1567	0.328	0.3986	0.3776	0.0739	0.2259
F12	0.2515	0.2971	0.3002	0.3261	0.1509	0.3228	0.336	0.2009	0.2818	0.1193	0.1258	0.2675	0.1698	0.2737	0.325
F13	0.2968	0.3348	0.3002	0.1409	0.296	0.2427	0.2661	0.245	0.1958	0.3111	0.2466	0.2675	0.1293	0.2737	0.2755
F14	0.1685	0.2971	0.2257	0.2764	0.1983	0.2427	0.2255	0.2891	0.16	0.3485	0.2466	0.1364	0.2534	0.1396	0.2755
F15	0.2515	0.2971	0.2664	0.1852	0.2427	0.1238	0.2661	0.1641	0.16	0.1193	0.2022	0.2675	0.2534	0.2737	0.2259

TABLE V
POSITIVE IDEAL SOLUTIONS ($R+$) AND NEGATIVE IDEAL SOLUTIONS ($R-$)

Factors	1	2	3	4	5	6	7	8	9	10	3	12	13	14	15
(R^+)	0.4351	0.3348	0.3905	0.3676	0.3492	0.4199	0.336	0.365	0.4131	0.4046	0.3674	0.3986	0.3776	0.364	0.325
(R^-)	0.0679	0.068	0.1151	0.1409	0.0799	0.1238	0.1511	0.1249	0.16	0.1193	0.1258	0.1364	0.1293	0.0739	0.0744

TABLE VI
WEIGHTS OF DIFFERENT CSFS

Weights	Value
W1	0.086
W2	0.085
W3	0.078
W4	0.136
W5	0.067
W6	0.121
W7	0.096
W8	0.035
W9	0.095
W10	0.053
W11	0.019
W12	0.037
W13	0.03
W14	0.027
W15	0.035

In third stage, positive ideal solution (PIS) is calculated by (1) and negative ideal solution (NIS) is calculated by (2) as shown in Table V.

In fourth stage, weights of different factors are taken by AHP methodology and shown in Table VI.

In fifth stage, weighted Euclidian distances are calculated by (3) and (4) and shown in Table VII

In sixth stage, relative closeness of each factor is calculated by (5) shown in Table VIII.

In last step, the factors are arranged in descending order of their relative closeness: 8-2-3-12-5-13-6-9-11-10-14-4-1-15-7.

VI. DISCUSSION AND CONCLUSION

The objective of research was to rank critical success factors so that leagile manufacturing system can be successfully implemented in industries. The factors have been identified through literature review and ranking of factors have been done by modified Topsis technique. It has been seen that use of advance manufacturing technology is the top most factor, it produces the better quality products, wastages are minimum and the customized products can be produced well on time. The second factor is management support towards implementation of policies; the management should support their employees in implementing leagile system. The employees, especially managers, should be empowered at least to some extent so that they can take decision on their own. The third critical success factor is strategic management. The manager should plan proper strategies to deal with the customers in market as well as should look properly in to the production system. He should take quick actions for the problems encountered while implementing leagile system. Similarly, the fourth critical success factor is training and development programs. The training and development programs on various topics like six sigma, kaizen, poke yoke, rapid reconfiguration, advance manufacturing technologies, CNC, robotics etc. should be organized time to time so that the employees should be well acquainted with the latest technologies and quality tools and techniques to make the system leagile.

TABLE VII
WEIGHTED EUCLIDIAN DISTANCE

Factors	1	2	3	4	5	6	7	8	9	10	3	12	13	14	15
(D^+)	0.1826	0.1187	0.1216	0.1765	0.1332	0.1490	0.1901	0.1120	0.1619	0.1495	0.1640	0.1334	0.1491	0.1648	0.1859
(D^-)	0.1340	0.1970	0.1759	0.1310	0.1480	0.1521	0.1084	0.1939	0.1550	0.1330	0.1480	0.1693	0.1591	0.1340	0.1248

TABLE VIII
RELATIVE CLOSENESS OF PARTICULAR FACTOR TO IDEAL SOLUTION ($P_{I\text{-}MOD}$)

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$(P_{i\text{-}mod})$	0.4231	0.6240	0.5912	0.4260	0.5262	0.5050	0.3631	0.6338	0.4890	0.4708	0.4744	0.5592	0.5161	0.4484	0.4017

TABLE IX
RANKING OF CRITICAL SUCCESS FACTORS

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ranking	8	2	3	12	5	13	6	9	11	10	14	4	1	15	7

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