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Leanness assessment of automobile industry using fuzzy based integrated approach

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ABSTRACT

The manufacturing industries are converting their production systems from mass to lean manufacturing. The lean techniques were described by the elimination of waste occurring during manufacturing, thereby moving towards a reduction in overall cost. The quantification of leanness is one of the contemporary research agendas of lean manufacturing. The main goal of this paper was to propose a scale for the measurement of the degree of leanness for an industry using fuzzy based approach. The data was collected from the Indian automobile industry. The Tukey's honestly significant difference test was implemented for verification of the final outcome. The final outcome demonstrated that value stream mapping came out to be the most significant lean manufacturing technique. It was also noticed that supplier partnership and 5S systems were found to have the least influence on the overall leanness index of automobile industry, which was facing low production issues and wanted to enhance their overall performance.

Keywords: lean manufacturing; degree of leanness; fuzzy DEMATEL; cluster analysis

1. INTRODUCTION

Lean manufacturing is gaining popularity as a manufacturing management tool for the significant continuous improvement in the performance level of an organization. However, the implementation of the lean manufacturing paradigm is not an easy task. It takes a considerably long time for its full implementation in an industry (Vimal and Vinodh, 2013; Yadav et al., 2019). Therefore, it is also known as the continuous improvement process for an organization. While implementing a lean process, continuous evaluation of the lean manufacturing process is required.

To assess the implementation level of lean manufacturing in an organization, it is required to measure the degree of leanness of that organization. But this is a complex task due to the multifaceted nature of the lean manufacturing approach. Moreover, there is a lack of availability of the manufacturing database to be used as a benchmark for leanness and subjective human judgment on lean manufacturing techniques. Many authors investigated the leanness of quality of auto parts based on six sigma approach with case study in manufacturing industries (Shahin and Jaberi, 2011; Dabestani et al., 2017). Silvério et al. (2020) worked on a leanness assessment review for the product development industry including performance measurement and improvement of lean manufacturing operations. The decision-making approaches have also been considered by various researchers for industrial performance (Shahin et al., 2021; Shahin and Rezaei, 2018; Mumani et al., 2022)

Lean production or lean thinking (Womack et al., 1990; Womack and Jones, 1997) is based on the concept of achieving improvements in most economical way with an emphasis on waste elimination and is in line with Ohno's Toyota production system. Lean employs minimum resources for maximum output, and it is based on five principles (Womack and Jones, 1997): specify the value for a specific product identify the value stream for each product make the value flow without interruptions let the customer pull value from the producer and pursue perfection.

According to Womack et al. (1990), top management should foster teamwork and focus on lean tools and techniques, creating a polyvalent organization that strives to identify problems and their causes instead of searching and punishing the responsible. For McDonald et al. (2002), the key areas of lean manufacturing are flexibility, elimination of waste, optimization, monitoring of processes, and involvement of people. Subsequently, several tools and techniques have been developed to facilitate lean implementation, such as value stream mapping to design the flow of value of a product (Rother and Shook, 2003).

The indicator of lean development is the leanness level for that particular industry. It is a decision-making issue that requires the use of fuzzy logic. Most of the lean development principles are embraced on time basis techniques like just in time (JIT), cellular manufacturing technology, and world class development (Kumar et al., 2020; Sharma and Singhal, 2017). Lean construction analysis of the concrete pouring process using value stream mapping and arena based simulation model also has been considered by some of researchers (Zahraee et al., 2021). Adoption of lean practices has many benefits, such as reduced stock, reduced lead times, increased efficiency in execution, increased use of space and energy, enhanced competitiveness and consistency (Dai and Chen, 2012). Elsisi et al. (2021a and 2021b) worked on learning-based industry 4.0 along with the internet of things for effective energy management for smart kinds of buildings. The fuzzy-logic based MPPT method has been implemented for grid-connected PV systems (Ali et al., 2021a and 2021b; Tran et al., 2021). Shahin and Alinavaz (2008) worked on a literature perspective of lean six sigma. A survey on lean manufacturing implementation in the selected manufacturing industry in Iran was conducted by Zahraee in 2016. Lean manufacturing analysis of the heater industry has been done by various researchers based on value stream mapping and computer simulation (Zahraee et al., 2020).

The lack of a benchmark and the uncertainty vagueness and biases in responses in the assessment of degree of leanness index have been considered using a practical example. The fuzzy-DEMATEL approach has been implemented for handling the current industrial problem. The expert's opinion has also been collected and taken into account for the development of scale. The required database has been collected through a survey of various Indian automobile industries.

In the present work, a methodology was proposed to deal with the multi-dimensional nature of lean manufacturing practices. The objective of this paper was to show that Indian industry must be able to know their leanness level and to motivate the Indian automobile industry to implement lean manufacturing techniques and improve their leanness level and productivity. In this leanness index scale is developed without any assumption of weights for different lean manufacturing techniques but earlier scales developed by the other authors have assumed some weights.

2. MATERIALS AND METHODS

2.1 Proposed methodology

In current work, the authors proposed a DEMATEL based approach for handling the problems, as it is useful for problems based on causal relationships between two or more factors or constructs. In the present work, a total of twelve lean manufacturing techniques were used for scale development. The cause-and-effect relationship among the factors was determined by the proposed approach. This method was particularly useful for visualizing the structure of complicated causal relationships (Büyüközkan and Cifci, 2012). This approach was best suited for these kinds of industrial problems (Baykasoğlu et al., 2013). The methodology adopted for the current study is demonstrated in Figure 1. In the adopted approach, there was no requirement to find initial weights.

Step 1: In the first step, a literature survey was conducted. Various papers were collected and studied for current study.
Step 2: Initial data was collected after a required survey. The data was collected from various industries through a survey. More than 100 industries were considered for the present work.
Step 3: At this stage, data were analyzed and arranged into the desired input form for the next stage.
Step 4: Fuzzy DEMATEL was implemented at this stage. The various steps of fuzzy DEMATEL were implemented.
Step 5: ANOVA was applied at this stage to get the ranking of the selected lean approaches.
Step 6: At last, the final ranking was found out.

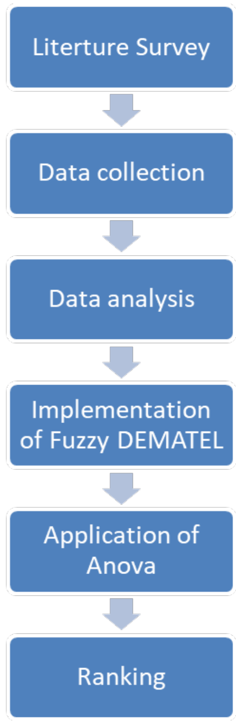

Figure 1. Flow chart of the methodology adopted for current work

2.2 Scale development

A Fuzzy DEMATEL was implemented for measuring the scale. The proposed approach started with the formation of a direct-relation matrix (Equation 1). This equation represented the relationships among the various factors. A typical ranking process involved the determination of relationships among a set of factors *F = {F1, F2, ..., Fn}*. The first step of the proposed approach was initiated by creating the direct relation fuzzy matrix *Z* where *Z* is (nxn) matrix, where the number of factors is represented by *n*. A pair-wise comparison among the factors was made to find out the degree of influence of factor *Fi* on factor *Fj*. This led to the formation of direct relationship matrices.

In the proposed method, the linguistic expression matrices were expressed in terms of the *Z* matrix, which is given in Equation 1 (Dalalah et al., 2011). It showed the effects of the factors on each other. Equation 2 represents the transformation of the direct relationship matrix (*Z*) into a normalized one (X) (Dalalah et al., 2011). The normalized direct-relation fuzzy matrix was represented by *X* was given by Equation 2.

$$Z=\begin{bmatrix} 0 & z_{12}\cdots\cdots\cdots\cdots & z_{1n} \\ z_{21} & 0\ \cdots\cdots\cdots\cdots & z_{2n} \\ \cdots\cdots & \cdots\cdots\quad 0 & \cdots\cdots \\ z_{n1} & z_{n2}\ \cdots\cdots\cdots\cdots & 0 \end{bmatrix} \quad (1)$$

$$X=\begin{bmatrix} x_{11} & x_{12}\cdots\cdots\cdots\cdots & x_{1n} \\ x_{21} & x_{22}\cdots\cdots\cdots\cdots & x_{2n} \\ \cdots\cdots & \cdots\cdots\quad\cdots\cdots & \cdots\cdots \\ x_{n1} & x_{n2}\ \cdots\cdots\cdots\cdots & x_{nn} \end{bmatrix} \quad (2)$$

where

$$x_{ij}=\frac{z_{ij}}{R}=\left(\frac{z_{ij,l}}{r_l},\frac{z_{ij,m}}{r_m},\frac{z_{ij,u}}{r_u}\right),\ R=(r_l,r_m,r_u)$$

$$r_s=\max\left(\sum_{1\le j\le n} z_{ij},s\right)_{1\le i\le n} \qquad \forall s=l,m,u$$

The linguistic measures of influence to make *Z* matrix were used as given in Appendix. In the current study, for assessing factors, the fuzzy triangular numbers (Table 1) were *1; 3; 5; 7; and 9*, with their respective spread as follows *(1, 1, 1), (2, 3, 4), (4, 5, 6), (6, 7, 8), (8, 9, 9)*. The initial normalized direct-relationship fuzzy matrix could be represented by separate sub matrices, i.e., (X_l, X_m, X_u) referred to in Appendix.

Therefore, the total relationship fuzzy matrix T (Equations 3 and 4) could be found by calculating the following term (Dalalah et al., 2011):

$$T=\lim_{w\to\infty}(x+x^2+\cdots+x^w); \quad (3)$$

$$T= X\,(I-X)^{-1} \quad (4)$$

Hence, T matrix could be denoted by Equation (5).

$$T=\begin{bmatrix} t_{11} & t_{12}\cdots\cdots\cdots\cdots & t_{1n} \\ t_{21} & t_{22}\cdots\cdots\cdots\cdots & t_{2n} \\ \cdots\cdots & \cdots\cdots\quad\cdots\cdots & \cdots\cdots \\ t_{n1} & t_{n2}\ \cdots\cdots\cdots\cdots & t_{nn} \end{bmatrix} \quad (5)$$

D_i and R_i represent the sum of rows and sum of columns of the sub-matrices T_l, T_m, and T_u denoted by the fuzzy numbers respectively. These are found using Equations 6 and 7, respectively (Dalalah et al., 2011):

$$D_i=\sum_{i=1}^{n} t_{ij}\ ;\ i=(1, 2,..., n) \quad (6)$$

$$R_i=\sum_{j=1}^{n} t_{ij}\ ;\ j=(1, 2,..., n) \quad (7)$$

After that defuzzification was required in order to get the weights of the factors. The signed distance method of defuzzification mentioned by Baykasoğlu et al. (2013) was has been used. Defuzzification was denoted by Equation 8.

$$S_{(xij,\,0)} = \tfrac{1}{4}(x_{ij,\,l}+ 2x_{ij,\,m}+ x_{ij,\,u}) \quad (8)$$

In the next stage, the significance of each factor was calculated with the help of Equation 9:

$$\omega_i=\{(D_i+R_i)^2+(D_i-R_i)^2\}^{1/2} \quad (9)$$

The significance of each factor that needed to be calculated as indicated by Equation 10 was then normalized.

$$W_i=\frac{\omega_i}{\sum_{i=1}^{n}\omega_i} \quad (10)$$

where W_i denotes the final weights of the factors to be used for the ranking process (Dalalah et al., 2011).

The next individual weights of each factor were used to calculate the leanness index (*Li*) by Equation 11:

$$Li=\sum_{i=1}^{n}(w_i * m_i);\ n = \text{number of factors.} \quad (11)$$

where, w_i is the weights of individual factors calculated through the fuzzy Dematel method as discussed above, and m_i is the mean values obtained from the survey questionnaire.

Table 1. Linguistic terms for factors comparison

Linguistic terms	Triangular fuzzy numbers	Linguistic values
No influence (No)	˜1	(1,1,1)
Very low influence (VL)	˜3	(2,3,4)
Low influence (L)	˜5	(4,5,6)
High influence (H)	˜7	(6,7,8)
Very high influence (VH)	˜9	(8,9,9)

2.3 Clustering of industries

The cluster analysis was implemented (K - means) for the clustering of the industries based upon their leanness index calculated using fuzzy DEMATEL. The validation of the cluster analysis was done by using one-way ANOVA on the basis of the leanness index of industries, and the results were verified by using their performance data. Post hoc (Tukey's honestly significant difference (HSD) test) was implemented for the validation of the clusters, that was, whether the groups were significantly differentiable or not.

3. RESULTS AND DISCUSSION

An initial influence matrix between all the lean manufacturing practices was constructed with the opinion of experts from the industry and academia. As demonstrated in Table 1, the initial influence matrix (*Z*) between selected factors was first constructed and then linguistic numerical values were assigned to it. The intermediate calculations for the low, medium, and upper fuzzy ranges were represented in Appendix.

After that, the initial influence matrix was normalized by using Equation 2 to get the matrix X. This was tabulated for low, medium, and upper fuzzy ranges, respectively, in Appendix I. Then a total relationship matrix (T) was generated with Equation 4, and this was tabulated for low, medium, and upper fuzzy ranges, respectively, in Appendix I. After that, the de-fuzzification of the matrix was carried out using Equation 8, and this was represented in Appendix. Thereafter, the weights of different factors, i.e., lean techniques were calculated with the help of Equation 10. Table 2 demonstrates the weights for lean techniques, and ranking was also has been done and represented in Table 3.

Table 2. Weights calculation of lean techniques

Technique	r + c	r-c	Ω	W	Rank
SMED	5.53177	0.096646	5.532614	0.079019	9
5S	4.706146	-0.38806	4.722118	0.067443	11
7W	6.599789	0.12532	6.600979	0.094277	2
GT	6.374839	0.040481	6.374967	0.091049	3
FP	5.869828	0.262057	5.875675	0.083918	8
FR	4.791619	1.245716	4.950901	0.07071	10
KB	6.325824	-0.0227	6.325865	0.090348	4
KZN	6.104951	0.349437	6.114943	0.087336	6
QMS	6.306419	-0.15588	6.308346	0.090098	5
SP	3.349008	-1.40851	3.633148	0.05189	12
TPM	5.909842	-0.12312	5.911124	0.084425	7
VSM	7.665975	-0.02139	7.666005	0.109488	1
			70.01668	1	

Table 3. Ranking of lean techniques

Technique	W	Rank
VSM	0.109488	1
7W	0.094277	2
GT	0.091049	3
KB	0.090348	4
QMS	0.090098	5
KZN	0.087336	6
TPM	0.084425	7
FP	0.083918	8
SMED	0.079019	9
FR	0.07071	10
5S	0.067443	11
SP	0.05189	12

The calculated weights were then multiplied with the respective means obtained from the actual questionnaire as per Equation 11 and summed to get the overall leanness index. This gave the value of leanness index of that particular organization (Table 4).

The leanness index for the case organization was 3.915, and was in the medium range lean organizations, as shown in Table 5. The leanness index for all the 135 industries was calculated and then cluster analysis was performed as shown in Table 6. Out of the 135 industries, 23 (cluster 1) were found to be low lean, 65 were medium lean (cluster 2), and 47 were high lean organizations (cluster 3).

The means and standard deviation were also mentioned in Table 5. In the low lean industries, most of these were with turnover less than Rs.5 crores, number of employees 20-50 (industry type: vendors to the main automobile company). In medium lean industries, most of these were with a turnover of less than Rs. 10 crores, number of employees: 50-150 (industry type: OEM to the main automobile company). On the other hand, in high lean industries, most of these were with a turnover of more than 100 crores and a number of employees of more than 150 (industry type, main automobile company). After the clustering of industries on the basis of leanness index value, the post hoc Tukey's HSD analysis was implemented for all the performance measures. The analysis showed that most of the clusters were found significantly differentiable on the basis of their performance (demonstrated in Table 6), but for performance parameters viz. profitability, sales, and space utilization, it was found to be less significant difference between low and medium lean companies. Low and high, as well as medium and high, lean industries did have a significant difference. The 5S was a tool in lean manufacturing and for measuring the leanness index of the automobile industry, it was also taken into consideration.

This meant that with the partial implementation of lean manufacturing techniques (i.e., low and medium lean industries), the performance of the industries under study with regard to sales, profitability, and space utilization did not improve appreciably. But as the level of implementation of lean manufacturing in the organizations increased (i.e., high lean industries), the level of performance parameters, viz., profitability, sales, and space utilization, enhanced. This motivated the industry to achieve full implementation of lean manufacturing practices.

Table 4. Leanness index calculation for the case organization

Rank	Lean technique	Weight	Mean	Index
1	VSM	0.109488	3.890167	0.425928
2	7W	0.094277	3.685	0.347412
3	GT	0.091049	4.0795	0.371435
4	KB	0.090348	3.6904	0.33342
5	QMS	0.090098	4.138167	0.372839
6	KZN	0.087336	3.9096	0.341447
7	TPM	0.084425	4.2536	0.359108
8	FP	0.083918	3.833333	0.321686
9	SMED	0.079019	3.911	0.309041
10	FR	0.07071	3.716167	0.262771
11	5S	0.067443	3.870333	0.261026
12	SP	0.05189	4.040667	0.209669
		1		3.915783

Table 5. Clustering of industries on the basis of leanness index

Leanness	N	Mean	Standard deviation	Standard error	95% Confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
1	23	3.0827	0.25297	0.05275	2.9733	3.1921	2.66	3.44
2	65	3.8190	0.16903	0.02097	3.7771	3.8609	3.49	4.10
3	47	4.4396	0.18713	0.02730	4.3847	4.4946	4.16	4.80
Total	135	3.9096	0.50601	0.04355	3.8235	3.9958	2.66	4.80

Table 6. ANOVA and *post hoc* analysis

Serial Number	Performance measure		Mean ± standard deviation	F (ANOVA)	Significance level	*Post hoc* Tukey HSD test		
						Cluster	*p*-value	Significant or not
1	COR	Low	2.9783±0.1670	36.829	$p<0.05$	Low vs Med	0.028	Significant
		Medium	3.3808±0.8840			Low vs High	0.00	Significant
		High	4.2181±0.2586			Med vs High	0.00	Significant
2	CSAT	Low	3.2174±0.5292	36.744	$p<0.05$	Low vs Med	0.047	Significant
		Medium	3.6115±0.8626			Low vs High	0.00	Significant
		High	4.516±0.3845			Med vs High	0.00	Significant
3	CTR	Low	3.0652±0.4897	47.692	$p<0.05$	Low vs Med	0.003	Significant
		Medium	3.5769±0.8124			Low vs High	0.00	Significant
		High	4.4787±0.2986			Med vs High	0.00	Significant
4	DLT	Low	2.9855±0.2558	29.697	$p<0.05$	Low vs Med	0.001	Significant
		Medium	3.6615±1.0433			Low vs High	0.00	Significant
		High	4.4326±0.3987			Med vs High	0.00	Significant
5	IM	Low	2.7826±0.8504	41.536	$p<0.05$	Low vs Med	0.00	Significant
		Medium	3.60±0.7715			Low vs High	0.00	Significant
		High	4.3245±0.3863			Med vs High	0.00	Significant
6	IP	Low	2.9130±0.4622	32.918	$p<0.05$	Low vs Med	0.002	Significant
		Medium	3.5846±1.0186			Low vs High	0.00	Significant
		High	4.4521±0.4907			Med vs High	0.00	Significant
7	IQ	Low	2.9304±0.4496	42.115	$p<0.05$	Low vs Med	0.00	Significant
		Medium	3.6677±0.8087			Low vs High	0.00	Significant
		High	4.3702±0.3798			Med vs High	0.00	Significant
8	PROF	Low	2.9022±0.1457	26.229	$p<0.05$	Low vs Med	0.243	Not significant
		Medium	3.2423±1.1101			Low vs High	0.00	Significant
		High	4.2606±0.6613			Med vs High	0.00	Significant
9	SALE	Low	2.9710±0.3748	26.113	$p<0.05$	Low vs Med	0.989	Not significant
		Medium	3.00±1.1039			Low vs High	0.00	Significant
		High	4.0922±0.5233			Med vs High	0.00	Significant
10	SU	Low	3.0326±1.0205	33.219	$p<0.05$	Low vs Med	0.306	Not significant
		Medium	3.3192±0.9191			Low vs High	0.00	Significant
		High	4.4043±0.4089			Med vs High	0.00	Significant

4. CONCLUSION

The various lean techniques were considered for current study. The value stream mapping came out to be the most significant lean manufacturing technique impacting the overall leanness index with maximum weightage. Furthermore, other lean manufacturing techniques like supplier partnership and 5S were found to have the least influence on the overall leanness index. Post hoc analysis, it was demonstrated that all the clusters were significantly differentiable for most of the considered performance measures, but for performance parameters viz. profitability, sales, and space utilization.

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APPENDIX: FUZZY DEMATEL CALCULATIONS

Table S1. Initial influence matrix with linguistic terms

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0	L	VH	H	L	H	H	L	L	VL	L	H
5S	VL	0	H	VL	VL	VL	L	VL	L	VL	H	H
7W	H	H	0	VH	H	H	H	H	H	H	H	VH
GT	H	L	H	0	H	VH	VH	H	H	VL	L	VH
FP	L	L	H	H	0	L	H	H	VH	VL	H	VH
FR	L	VL	H	VH	L	0	H	H	H	VL	H	VH
KB	H	L	H	H	H	L	0	H	H	H	H	VH
KZN	H	L	H	H	H	H	H	0	H	H	H	VH
QMS	L	L	H	H	H	L	H	H	0	H	H	VH
SP	NO	NO	NO	NO	NO	NO	NO	NO	L	0	NO	H
TPM	L	H	H	H	L	L	H	L	H	VL	0	VH
VSM	VH	VH	VH	VH	VH	H	VH	VH	VH	H	VH	0

Table S2. Initial influence matrix with linguistic values (low)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0	4	8	6	4	6	6	4	4	2	4	6
5S	2	0	6	2	2	2	4	2	4	2	6	6
7W	6	6	0	8	6	6	6	6	6	6	6	8
GT	6	4	6	0	6	8	8	6	6	2	4	8
FP	4	4	6	6	0	4	6	6	8	2	6	8
FR	4	2	6	8	4	0	6	6	6	2	6	8
KB	6	4	6	6	6	4	0	6	6	6	6	8
KZN	6	4	6	6	6	6	6	0	6	6	6	8
QMS	4	4	6	6	6	4	6	6	0	6	6	8
SP	1	1	1	1	1	1	1	1	4	0	1	6
TPM	4	6	6	6	4	4	6	4	6	2	0	8
VSM	8	8	8	8	8	6	8	8	8	6	8	0

Table S3. Initial influence matrix with linguistic values (medium)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0	5	9	7	5	7	7	5	5	3	5	7
5S	3	0	7	3	3	3	5	3	5	3	7	7
7W	7	7	0	9	7	7	7	7	7	7	7	9
GT	7	5	7	0	7	9	9	7	7	3	5	9
FP	5	5	7	7	0	5	7	7	9	3	7	9
FR	5	3	7	9	5	0	7	7	7	3	7	9
KB	7	5	7	7	7	5	0	7	7	7	7	9
KZN	7	5	7	7	7	7	7	0	7	7	7	9
QMS	5	5	7	7	7	5	7	7	0	7	7	9
SP	1	1	1	1	1	1	1	1	5	0	1	7
TPM	5	7	7	7	5	5	7	5	7	3	0	9
VSM	9	9	9	9	9	7	9	9	9	7	9	0

Table S4. Initial influence matrix with linguistic values (high)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0	6	9	8	6	8	8	6	6	4	6	8
5S	4	0	8	4	4	4	6	4	6	4	8	8
7W	8	8	0	9	8	8	8	8	8	8	8	9
GT	8	6	8	0	8	9	9	8	8	4	6	9
FP	6	6	8	8	0	6	8	8	9	4	8	9
FR	6	4	8	9	6	0	8	8	8	4	8	9
KB	8	6	8	8	8	6	0	8	8	8	8	9
KZN	8	6	8	8	8	8	8	0	8	8	8	9
QMS	6	6	8	8	8	6	8	8	0	8	8	9
SP	1	1	1	1	1	1	1	1	6	0	1	8
TPM	6	8	8	8	6	6	8	6	8	4	0	9
VSM	9	9	9	9	9	8	9	9	9	8	9	0

Table S5. Initial influence matrix normalized (low)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0	0.047619	0.095238	0.071429	0.047619	0.071429	0.071429	0.047619	0.047619	0.02381	0.047619	0.071429
5S	0.02381	0	0.071429	0.02381	0.02381	0.02381	0.047619	0.02381	0.047619	0.02381	0.071429	0.071429
7W	0.071429	0.071429	0	0.095238	0.071429	0.071429	0.071429	0.071429	0.071429	0.071429	0.071429	0.095238
GT	0.071429	0.047619	0.071429	0	0.071429	0.095238	0.095238	0.071429	0.071429	0.02381	0.047619	0.095238
FP	0.047619	0.047619	0.071429	0.071429	0	0.047619	0.071429	0.071429	0.095238	0.02381	0.071429	0.095238
FR	0.047619	0.02381	0.071429	0.095238	0.047619	0	0.071429	0.071429	0.071429	0.02381	0.071429	0.095238
KB	0.071429	0.047619	0.071429	0.071429	0.071429	0.047619	0	0.071429	0.071429	0.071429	0.071429	0.095238
KZN	0.071429	0.047619	0.071429	0.071429	0.071429	0.071429	0.071429	0	0.071429	0.071429	0.071429	0.095238
QMS	0.047619	0.047619	0.071429	0.071429	0.071429	0.047619	0.071429	0.071429	0	0.071429	0.071429	0.095238
SP	0.011905	0.011905	0.011905	0.011905	0.011905	0.011905	0.011905	0.011905	0.047619	0	0.011905	0.071429
TPM	0.047619	0.071429	0.071429	0.071429	0.047619	0.047619	0.071429	0.047619	0.071429	0.02381	0	0.095238
VSM	0.095238	0.095238	0.095238	0.095238	0.095238	0.071429	0.095238	0.095238	0.095238	0.071429	0.095238	0

Table S6. Initial influence matrix normalized (medium)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0	0.052632	0.094737	0.073684	0.052632	0.073684	0.073684	0.052632	0.052632	0.031579	0.052632	0.073684
5S	0.031579	0	0.073684	0.031579	0.031579	0.031579	0.052632	0.031579	0.052632	0.031579	0.073684	0.073684
7W	0.073684	0.073684	0	0.094737	0.073684	0.073684	0.073684	0.073684	0.073684	0.073684	0.073684	0.094737
GT	0.073684	0.052632	0.073684	0	0.073684	0.094737	0.094737	0.073684	0.073684	0.031579	0.052632	0.094737
FP	0.052632	0.052632	0.073684	0.073684	0	0.052632	0.073684	0.073684	0.094737	0.031579	0.073684	0.094737
FR	0.052632	0.031579	0.073684	0.094737	0.052632	0	0.073684	0.073684	0.073684	0.031579	0.073684	0.094737
KB	0.073684	0.052632	0.073684	0.073684	0.073684	0.052632	0	0.073684	0.073684	0.073684	0.073684	0.094737
KZN	0.073684	0.052632	0.073684	0.073684	0.073684	0.073684	0.073684	0	0.073684	0.073684	0.073684	0.094737
QMS	0.052632	0.052632	0.073684	0.073684	0.073684	0.052632	0.073684	0.073684	0	0.073684	0.073684	0.094737
SP	0.010526	0.010526	0.010526	0.010526	0.010526	0.010526	0.010526	0.010526	0.052632	0	0.010526	0.073684
TPM	0.052632	0.073684	0.073684	0.073684	0.052632	0.052632	0.073684	0.052632	0.073684	0.031579	0	0.094737
VSM	0.094737	0.094737	0.094737	0.094737	0.094737	0.073684	0.094737	0.094737	0.094737	0.073684	0.094737	0

Table S7. Initial influence matrix normalized (high)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0	0.061856	0.092784	0.082474	0.061856	0.082474	0.082474	0.061856	0.061856	0.041237	0.061856	0.082474
5S	0.041237	0	0.082474	0.041237	0.041237	0.041237	0.061856	0.041237	0.061856	0.041237	0.082474	0.082474
7W	0.082474	0.082474	0	0.092784	0.082474	0.082474	0.082474	0.082474	0.082474	0.082474	0.082474	0.092784
GT	0.082474	0.061856	0.082474	0	0.082474	0.092784	0.092784	0.082474	0.082474	0.041237	0.061856	0.092784
FP	0.061856	0.061856	0.082474	0.082474	0	0.061856	0.082474	0.082474	0.092784	0.041237	0.082474	0.092784
FR	0.061856	0.041237	0.082474	0.092784	0.061856	0	0.082474	0.082474	0.082474	0.041237	0.082474	0.092784
KB	0.082474	0.061856	0.082474	0.082474	0.082474	0.061856	0	0.082474	0.082474	0.082474	0.082474	0.092784
KZN	0.082474	0.061856	0.082474	0.082474	0.082474	0.082474	0.082474	0	0.082474	0.082474	0.082474	0.092784
QMS	0.061856	0.061856	0.082474	0.082474	0.082474	0.061856	0.082474	0.082474	0	0.082474	0.082474	0.092784
SP	0.010309	0.010309	0.010309	0.010309	0.010309	0.010309	0.010309	0.010309	0.061856	0	0.010309	0.082474
TPM	0.061856	0.082474	0.082474	0.082474	0.061856	0.061856	0.082474	0.061856	0.082474	0.041237	0	0.092784
VSM	0.092784	0.092784	0.092784	0.092784	0.092784	0.082474	0.092784	0.092784	0.092784	0.082474	0.092784	0

Table S8. Total influence matrix (low)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0.127614	0.162516	0.243377	0.220791	0.177565	0.192909	0.219614	0.181852	0.197853	0.127742	0.188354	0.255783
5S	0.114166	0.085447	0.177223	0.132865	0.117664	0.111724	0.153518	0.120147	0.153935	0.098772	0.169197	0.200958
7W	0.222372	0.210313	0.190996	0.274743	0.228159	0.220603	0.254153	0.233062	0.254651	0.194257	0.241674	0.320786
GT	0.217228	0.182767	0.250627	0.181821	0.222836	0.23588	0.268001	0.228078	0.246757	0.146827	0.21471	0.310365
FP	0.187301	0.176514	0.239668	0.237093	0.147701	0.184795	0.236852	0.218474	0.257616	0.14073	0.226074	0.297779
FR	0.18542	0.152018	0.235938	0.255593	0.190718	0.137997	0.234119	0.216007	0.233146	0.137665	0.222017	0.293511
KB	0.210887	0.178753	0.242912	0.239848	0.216355	0.18759	0.172917	0.220523	0.240566	0.18574	0.228209	0.3029
KZN	0.215008	0.182131	0.248155	0.245528	0.220593	0.212879	0.244786	0.158657	0.245747	0.1888	0.233143	0.309423
QMS	0.185829	0.175141	0.237504	0.234941	0.212409	0.183303	0.234703	0.216482	0.169503	0.182902	0.224024	0.297216
SP	0.059804	0.056691	0.070059	0.069058	0.062127	0.058075	0.069005	0.063418	0.102199	0.040321	0.065866	0.135945
TPM	0.176768	0.188773	0.227488	0.2241	0.181856	0.174367	0.224344	0.185731	0.223862	0.131537	0.147985	0.282147
VSM	0.27058	0.257037	0.31309	0.308116	0.277597	0.247724	0.308212	0.283102	0.308762	0.217219	0.294217	0.276138

Table S9. Total influence matrix (medium)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0.15336	0.193012	0.269403	0.248829	0.207977	0.220703	0.247883	0.212305	0.23085	0.162765	0.219295	0.287149
5S	0.147039	0.110172	0.206809	0.167287	0.150787	0.144928	0.185438	0.153629	0.187403	0.131872	0.197763	0.234421
7W	0.250421	0.238761	0.216842	0.299935	0.256117	0.248829	0.281759	0.260996	0.28484	0.225681	0.269768	0.348167
GT	0.245058	0.213887	0.278528	0.207296	0.250594	0.261481	0.293202	0.255722	0.276807	0.182807	0.245246	0.338023
FP	0.217622	0.20702	0.267811	0.264902	0.173324	0.215463	0.264679	0.246177	0.285128	0.176045	0.254083	0.325778
FR	0.215264	0.184986	0.263936	0.28045	0.220524	0.16352	0.261587	0.243338	0.262968	0.172805	0.249995	0.32135
KB	0.238512	0.209172	0.270778	0.267483	0.243923	0.218046	0.198617	0.248199	0.270581	0.216123	0.25618	0.330641
KZN	0.242732	0.212799	0.275953	0.272982	0.248247	0.24086	0.272374	0.184343	0.275738	0.219511	0.261082	0.336942
QMS	0.215897	0.205387	0.265496	0.262604	0.239845	0.213719	0.262384	0.244036	0.197427	0.212931	0.25188	0.325011
SP	0.063956	0.061068	0.073696	0.072716	0.066203	0.062377	0.072671	0.067426	0.112351	0.047072	0.069763	0.142942
TPM	0.207245	0.216529	0.255999	0.252486	0.212332	0.205167	0.25264	0.216355	0.254326	0.166699	0.174293	0.311007
VSM	0.297005	0.284032	0.338232	0.333331	0.303741	0.276885	0.333375	0.30917	0.336791	0.250411	0.320048	0.302993

Table S10. Total influence matrix (high)

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0.252592	0.296387	0.377372	0.360866	0.317676	0.327678	0.363234	0.323917	0.351795	0.269449	0.33471	0.405801
5S	0.242641	0.192949	0.311023	0.268524	0.248359	0.241041	0.288546	0.25295	0.294473	0.225544	0.298975	0.341485
7W	0.365934	0.350027	0.336039	0.411606	0.373991	0.364629	0.405997	0.380936	0.414903	0.340936	0.393934	0.465912
GT	0.354797	0.320552	0.398737	0.314204	0.362563	0.36229	0.401769	0.369463	0.399918	0.29339	0.363568	0.44848
FP	0.327499	0.31268	0.387713	0.379479	0.276978	0.325883	0.382253	0.359376	0.398154	0.285422	0.371128	0.436428
FR	0.323049	0.289588	0.381778	0.383337	0.330496	0.2633	0.376836	0.354559	0.383549	0.280752	0.365246	0.429887
KB	0.35178	0.318736	0.395235	0.386674	0.359512	0.332525	0.313306	0.365846	0.39818	0.328498	0.377819	0.446948
KZN	0.357933	0.324252	0.402507	0.393975	0.365807	0.356587	0.396674	0.296409	0.405486	0.333846	0.384776	0.455136
QMS	0.327921	0.31309	0.388047	0.3798	0.353461	0.326283	0.382578	0.359676	0.315289	0.323366	0.371444	0.439219
SP	0.093061	0.089037	0.105775	0.103381	0.096043	0.092071	0.104177	0.097797	0.153613	0.076849	0.101147	0.183068
TPM	0.315942	0.320289	0.37489	0.366244	0.323241	0.314367	0.369268	0.329229	0.375929	0.274843	0.282697	0.421767
VSM	0.395899	0.379069	0.44582	0.435527	0.404604	0.385614	0.438977	0.411949	0.448293	0.36019	0.426212	0.408806

Table S11. Defuzzified matrix

Technique	SMED	5S	7W	GT	FP	FR	KB	KZN	QMS	SP	TPM	VSM
SMED	0.171732	0.211232	0.289889	0.269829	0.227799	0.158579	0.269653	0.232595	0.252837	0.18068	0.240413	0.30897
5S	0.162721	0.124685	0.225466	0.183991	0.166899	0.100395	0.203235	0.170089	0.205803	0.147015	0.215924	0.252821
7W	0.272287	0.259466	0.24018	0.321555	0.278596	0.179565	0.305917	0.283998	0.309809	0.246639	0.293786	0.370758
GT	0.265536	0.232773	0.301605	0.227655	0.271647	0.189711	0.314043	0.277246	0.300072	0.201458	0.267192	0.358722
FP	0.237511	0.225808	0.290751	0.286594	0.192832	0.15393	0.287116	0.267551	0.306506	0.19456	0.276342	0.346441
FR	0.234749	0.202895	0.286397	0.299957	0.240565	0.116259	0.283532	0.26431	0.285657	0.191007	0.271813	0.341524
KB	0.259923	0.228958	0.294926	0.290372	0.265928	0.155921	0.220864	0.270692	0.294977	0.236621	0.279597	0.352783
KZN	0.264602	0.232995	0.300642	0.296367	0.270724	0.17365	0.296552	0.205938	0.300677	0.240417	0.285021	0.359611
QMS	0.236386	0.224751	0.289135	0.284987	0.26139	0.152685	0.285512	0.266057	0.219912	0.233032	0.274807	0.346614
SP	0.070194	0.066966	0.080807	0.079467	0.072644	0.045707	0.079631	0.074017	0.120128	0.052829	0.076634	0.151224
TPM	0.2268	0.23553	0.278594	0.273829	0.23244	0.146175	0.274723	0.236917	0.277111	0.184945	0.194817	0.331482
VSM	0.315123	0.301042	0.358843	0.352576	0.322421	0.200373	0.353485	0.328348	0.357659	0.269558	0.340132	0.322732