An approach to evaluate interrelationships among lean attributes of manufacturing systems: A case study based on lean enterprises

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***Abstract*—Lean philosophy has received more emphasize during recent times due to its robust features which facilitate productive manufacturing environments in companies regardless of the type of industry. However, enormous approaches taken to implement lean manufacturing systems inside factories, have failed to achieve desired objectives. This is mainly due to the focus on individual lean attributes rather than considering their collective impact on a system. This paper suggested an approach to measure correlations among lean attributes using their degrees of implementation. These correlations will help organizations to identify lean attributes which are interrelated. The quest is how to measure the degree to which each lean attribute has been implemented within the organization. Different companies have varying levels of lean implementations. Therefore identifying the leanness requires the organization to compare itself against a proxy company who has also implemented similar lean attributes. This research suggested an approach to identify a proxy company and then evaluate the degrees of lean attribute implementations of the selected company. The fuzzy membership functions were used to calculate the degrees. These degrees were then used to figure out possible correlations among lean attributes. The research findings showed that visual feedback made available to the factory floor had triggered a positive impact on other lean attributes in most circumstances.**

Keywords*—lean philosophy; lean attributes; correlations; degrees of implementation; proxy company; fuzzy membership functions

I. Introduction

A number of lean manufacturing related techniques and attributes have been introduced and implemented in manufacturing organizations to boost performance of systems. However, there are continuous struggles to establish a sound lean enterprise considering optimal combination of lean attributes. This research provides a basis to quantify correlations among lean attributes and thereby to identify their underlying relationships. The integrity among lean attributes should be clearly known to decide upon what attributes to be implemented. This will help avoid overemphasizing on certain lean attributes which do not really add value to the company. The research requires a company to identify the extent to which each attribute has been implemented within the system. This primarily depends on the lean policy adopted by the company.

The company may have adopted the best lean policy or average lean policy or zero lean policy. An organization can consider two options in determining the type of lean policy. One option is to use an internally developed lean measurement scale. The scale is developed considering the company's own past information. The degrees of implementation in each period can be figured out against a base period. The other option is to use an external organization to measure the degrees. This involves identifying a proxy company and then determines the relative degrees of implementation based on a benchmarked lean measurement scale. This scale should be developed for each lean attribute irrespective of the option used. The latter method was used in this study since the organization can effectively compare their leanness against an external entity and make improvements to their portfolio of lean tools.

The research focuses on answering three major questions to accomplish stated objectives. Firstly, it identifies a proxy company to compare the leanness of the organization in consideration. Secondly, it tries to figure out the methods available to evaluate the degrees of implementation of each lean attribute. Thirdly, it determines most probable correlations exist among lean attributes. This helps achieve the ultimate research objective of identifying the lean attributes which are interrelated.

The sample is selected based on a group of lean enterprises which have implemented a number of lean disciplines and also have been exercising lean manufacturing techniques over a decade. This paper is organized into sections to achieve the desired research objectives. Section 2 critically reviews the relevant literature and identifies the gaps between existing lean performance measurement models. Section 3 discusses the use of fuzzy membership functions to evaluate performance of each lean attribute. Finally, section 4 concludes the study by highlighting possible relationships among lean attributes.

II. Literature Review

A. History of the lean manufacturing

Henry Ford, the one who first pioneered the concept of integrating the entire production process, introduced standard work and moving assembly line to the world of manufacturing. The system introduced by Henry Ford had critical drawbacks.

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One such problem was its inability to provide a variety of products for the customers. Therefore, up until 1926 the Model T, the first affordable automobile, was available only in one color and also limited to one set of specifications. This enabled Ford to run their machines without any changeovers. This method of mass production was not suited when the world required more variety. Therefore, companies were forced to create a variety in their production and this caused them to experience longer throughput times and larger inventories due to highly customized products. In the 1930s Kiichiro Toyoda, Taiichi Ohno, and a group of people at Toyota looked at different alternatives available to maintain the continuity of process flow while offering a wide variety of automobiles to the market. This effort steered them to invent Toyota Production System (TPS) [1].

B. Lean principles

In the publication of Lean Thinking [2] the lean philosophy has been reduced to five principles; specify the value required by the customer, eliminate non-value adding activities, ensure continuous flow, enable pull between each step of production, and support continuous improvement. Lean mainly focuses on reducing seven types of waste [3]; transport, inventory, motion, waiting, over-processing, over-production, and defects. Waste elimination is made possible by a variety of lean attributes evolved over the last two decades. There are 26 lean attributes [4] selected for this study and the list is given in part B.

C. Measuring lean performance

There are various models developed to measure lean performance. A conceptual model [5], which was developed to measure lean practices, has identified seven dimensions and factors pertaining to these dimensions considering 25 articles. However, this model does not really provide a basis to quantify lean attributes. The whole study was limited to identifying factors influencing leanness of a company.

A different model called probabilistic approach [6] has suggested measuring leanness using opinions of decision makers. This study was conducted in order to identify the success possibility of lean implementation in a particular company. This model groups companies into three categories; lean, leaner, too lean. Even though this model measures the leanness of a company, the results can be subjective due to the opinions of decision makers.

A dynamic and innovative approach for lean performance evaluation [7] was developed based on fuzzy membership functions. This method is capable of producing a lean score which measures the leanness of a company. Moreover, each lean attribute was measured in terms of performance metrics which are identified through extensive literature surveys [7, 8]. However, when measuring performances, this model has used self-benchmarking (internal benchmarking) which means that the best performing level of each lean attribute was determined based on the company's own historical data. Therefore, this model ignores the opportunity to benchmark with external entity and thereby only aiming at internal performance levels.

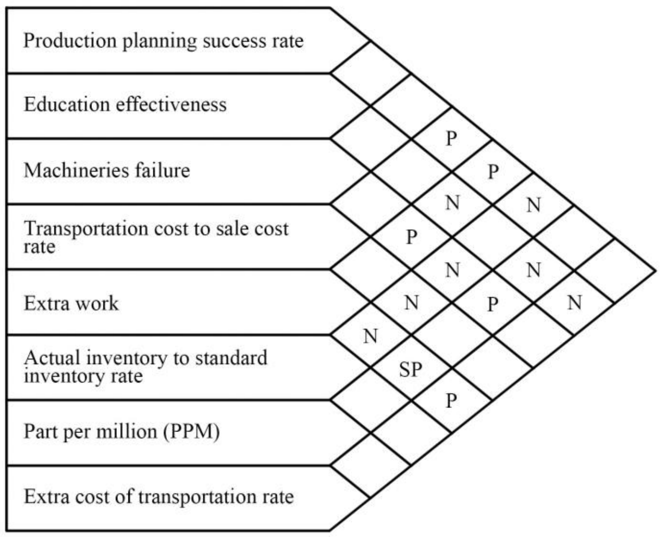
D. Factors influencing lean performance and benchmarking

An effective performance measurement system should be capable of assessing performance against a benchmarked performance. This requires a proxy company to be identified which operates in the same scale. The performance of any company is influenced by its organizational culture. Since organizational culture is a sub culture of national culture of that country, the lean performance is dependent on the dimensions of national culture. The survey conducted taking 1,400 factories in 24 countries shows that lean manufacturing is most effective in countries that value high uncertainty avoidance, low assertiveness, low future orientation, and low performance orientation [9]. This indicates when identifying a similar company to benchmark, the focus should be given to the culture of the organization. Therefore, the culture of the benchmarking company should be similar to that of the targeted company to effectively compare the lean performances.

A successful use of lean manufacturing practices requires more than the use of a variety of lean tools. The availability of critical success factors (CSFs) is also essential for a successful lean implementation. Lean is a philosophy whose success depends on the commitment and the thinking of people. There are four key factors have been identified for a successful lean implementation [10]; preparation and motivation of people, role in the change process, methodologies for change, and environment for change. These factors should be equally available in benchmarking company and so as the targeted company to make the comparison more effective.

E. Interrelationships among lean attributes

There are a few studies which support determining mutual effect of lean attributes. Some correlations exist among lean attributes are depicted in Fig. 1 [11]. However, in these studies, the correlations are not quantified and also the number of lean attributes used is not adequate enough to identify all possible relationships among them.



SP – Strong positive, P – Positive, N – Negative, SN – Strong negative

Fig. 1. Correlations among lean attributes.

III. The Proposed Model To Determine Interrelationships Among Lean Attributes

This model consists of different phases and they are illustrated as follows:

A. Phase 1: Identifying a proxy company for benchmarking

A five-step procedure is carried out to select a similar entity to the targeted company (i.e. Sri Lanka/SL subsidiary). The steps involved are discussed at each step below.

1) Step 1: The proxy company should belong to the same industrial discipline. Therefore 11 other companies which are subsidiaries of the same parent company and are located in Asia-Pacific region were selected to the study.

2) Step 2: The proxy company and SL subsidiary should possess relatively similar manufacturing systems. The criterion used to assess the similarity was the degree of factory automation. The factory automation is subject to differ over a passage of time and therefore, two readings (at the beginning and end of the year) were taken from each company for the year and the derived mean value is considered the annual mean degree of automation. The countries are grouped into homogeneous subsets by conducting Tukey's post-hoc test (one of the techniques available in one-way ANOVA (analysis of variance) test to compare means of different groups). The grouping of companies based on their factory automation is demonstrated in Table 1.

TABLE I. Degree Of Factory Automation

No	**Subsidiary**	**Subset for alpha = 0.05**						
		1	***2***	***3***	***4***	***5***	***6***	***7***
9	W	44%						
7	U		65%					
6	T		66%	66%				
2	P		67%	67%	67%			
1	SL		68%	68%	68%	68%		
5	S			69%	69%	69%		
3	Q				69%	69%		
8	V					71%		
11	Y					71%		
10	X						82%	
4	R							91%
12	Z							92%
Sig		1.0	.066	.066	.172	.172	1.0	1.0

The twelve companies are grouped into seven categories. This indicates that SL subsidiary falls into four different groups (i.e. 2, 3, 4 and 5) and thereby it is relatively similar to seven other countries (i.e. U, T, P, S, Q, V and Y) in terms of the degree of automation.

Fig. 2 depicts the distribution of companies across varying degrees of automation. The degrees of automation of SL subsidiary and seven other countries are ranging from 60% to 80%. Therefore, the companies which are automated below 60% and above 80% are excluded from the analysis.

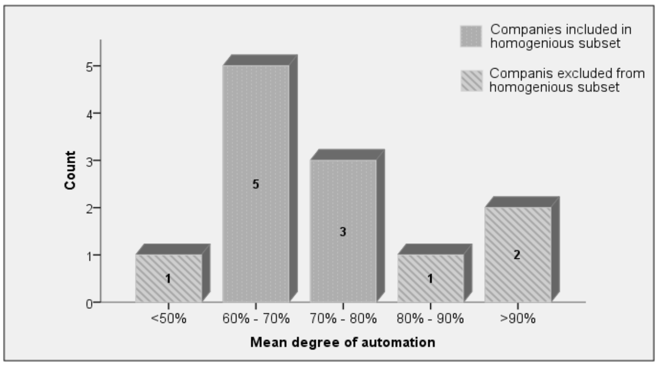


Fig. 2. Degree of factory automation.

3) Step 3: The seven companies identified in step 2 are further tested for homogeneity considering their manufacturing processes. Table 2 illustrates the five criteria used to compare the process similarity among different companies.

The evaluation criterion is as same as in step 2. The subsidiaries are grouped comparing means of the five criteria. The companies which had relatively similar mean values to SL subsidiary in most respects are considered most appropriate firms for benchmarking. Table 2 shows a comparison between each subsidiary and SL subsidiary in terms of different criteria evaluated.

TABLE II. Comparison Of Process Parameters

Criterion	**Subsidiary (categorized as either 1[a] or 0[b])**						
	P	***Q***	***S***	***T***	***U***	***V***	***Y***
1. Number of operators per machine	1	1	1	1	1	1	0
2. Finished goods per man hour	1	0	0	1	1	0	0
3. Product rejects level	1	0	0	1	1	1	0
4. Number of stock keeping units produced	0	0	0	0	0	1	0
5. Brand changeovers per machine	0	1	0	0	0	0	0

[a.] 0– Belongs to a group exclusive of SL subsidiary

[b.] 1– Belongs to a group inclusive of SL subsidiary

According to the Table 3, the subsidiaries based in P, T, U, and V countries are more similar to SL subsidiary. Therefore, Q, S, and Y subsidiaries are eliminated from further testing.

4) Step 4: The final objective of the phase 1 is to find out the most similar lean enterprise for benchmarking. Previous tests were able to sort companies mainly based on operational parameters. However, this step evaluates the leanness of companies in terms of degree of implementation of different lean attributes. A five-point rating scale is used to record responses regarding degree of implementation (i.e. 0 – Not at all, 1 – Slight/bit, 2 – Quite/reasonable, 3 – Moderately, 4 – Very). The judgments regarding lean implementation are collected from managers of each subsidiary. After gathering responses from each company, two companies are taken at a time (i.e. SL subsidiary and a similar other entity) to perform Mann-Whitney U test (2 samples). In this test each company is compared against SL subsidiary and performed a series of hypothesis tests to see whether there is a statistically significant difference between the degrees at which each lean tool implemented within two entities. The generic null hypothesis and the alternative hypothesis used in these tests were as follows:

a) Null hypothesis: There is no significant difference between the degrees of implementation of a particular lean tool (i.e. 5S, Kanban, JIT, etc.) between two companies

b) Alternative hypothesis: There is a significant difference between the degrees of implementation of a particular lean tool (i.e. 5S, Kanban, JIT, etc.) between two companies

If the significance (p-value) is greater than 0.05, the null hypothesis should be accepted and if it is less than 0.05, the alternative hypothesis should be accepted. Therefore, 26 hypothesis tests (to test 26 lean tools) are carried out for each of the four companies and only a sample of test results are demonstrated in Fig. 3.

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of 5S is the same across categories of Country.	Independent-Samples Mann-Whitney U Test	.165[1]	Retain the null hypothesis.
2	The distribution of Andon is the same across categories of Country.	Independent-Samples Mann-Whitney U Test	.206[1]	Retain the null hypothesis.
3	The distribution of Bottleneck Analysis is the same across categories of Country.	Independent-Samples Mann-Whitney U Test	.040[1]	Reject the null hypothesis.

Fig. 3. The summary (sample) of hypothesis tests conducted between SL and V subsidiaries.

The test is carried out for each subsidiary (i.e. P, T, U and V). The companies which had retained the null hypothesis in most of the instances are considered similar entities to SL subsidiary. Table 3 demonstrates the test summary.

TABLE III. SIMILARITY OF EACH SUBSIDIARY TO SL SUBSIDIARY

Subsidiary	Similarity (%)[a]
P	92%
T	81%
U	88%
V	92%

a. Similarity (%) = (Number of times that null hypothesis was accepted/Total hypotheses)×100

The subsidiaries based in country P and V are equally similar (i.e. 92%) to SL subsidiary.

5) Step 5: This step tests the lean culture of each company considering 21 parameters [12] to obtain the closest subsidiary to SL subsidiary. These 21 parameters can also be considered as critical success factors (CSF) which essentially required implementing lean principles successfully. The same five-point rating scale is used to identify the degree of availability as in step 4. After gathering responses from each company, two companies are taken at a time (i.e. SL subsidiary and a similar other entity) to perform Mann-Whitney U test (2 samples). In this test each company is compared against SL subsidiary and performed a series of hypothesis tests to see whether there is a statistically significant difference between the availability of each CSF within two entities. The generic null hypothesis and the alternative hypothesis used in these tests were as follows:

a) Null hypothesis: There is no significant difference between the availability of a particular CSF between two companies

b) Alternative hypothesis: There is a significant difference between the availability of a particular CSF between two companies

If p-value is greater than 0.05, the null hypothesis should be accepted and if it is less than 0.05, the alternative hypothesis should be accepted. Therefore, 21 hypothesis tests (to test 21 critical success factors) are carried out for each company and only a sample of test results are demonstrated in Fig. 4.

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Stakeholder involvement is the same across categories of Country.	Independent-Samples Mann-Whitney U Test	.594[1]	Retain the null hypothesis.
2	The distribution of Availability of crisis is the same across categories of Country.	Independent-Samples Mann-Whitney U Test	.768[1]	Retain the null hypothesis.
3	The distribution of Employee development is the same across categories of Country.	Independent-Samples Mann-Whitney U Test	.768[1]	Retain the null hypothesis.

Fig. 4. The summary (sample) of hypothesis tests conducted between SL and P subsidiaries.

The test is carried out for each subsidiary (i.e. P and V). The companies which had retained the null hypothesis in most of the instances are considered similar entities to SL subsidiary. Table 4 demonstrates the test summary.

TABLE IV. SIMILARITY OF EACH SUBSIDIARY TO SL SUBSIDIARY

Subsidiary	Similarity (%)[a]
P	100%
V	92%

a. Similarity (%) = (Number of times that null hypothesis was accepted/Total hypotheses)×100

According to the test results, P subsidiary is considered the most appropriate company for benchmarking.

B. Phase 2: Measuring degrees of lean implementation

Each lean attribute is represented by one or few performance metrics. Therefore measuring lean performance refers to figuring out values for these metrics. The research is based on 26 lean attributes and 42 performance metrics. Table

5 provides a sample of those metrics which was identified after undertaking a thorough literature survey.

TABLE V. LEAN ATTRIBUTES AND PERFORMANCE METRICS

Lean attribute	Metric	Performance metric
5S	M_1	5S radar chart
Andon	M_2	(Total time spent to identification/Number of issues identified)
Bottleneck Analysis	M_3	(Change in capacity/ Previous capacity)×100
Continuous Flow	M_4	(Finished goods produced / Total production time)
	M_5	Value of closing WIP at the month end
Gemba	M_6	Number of process observations per month per manager
Heijunka	M_7	(Total production volume/Number of batches)
Hoshin Kanri	M_8	Number of meetings held per month
Just-In-Time	M_{10}	Average total number of days from orders received to delivery
	M_{11}	(Number of machine stops by operator/Number of problems occurred)
Kaizen	M_{12}	Number of suggestions per employee per month
	M_{13}	Percentage of suggestions that get implemented
Kanban	M_{14}	Percentage of line processes that pull their inputs from their predecessors
	M_{15}	Percentage of the total annual value of output that is scheduled through pull system

Performances of these metrics are calculated for P and SL subsidiaries for a one-year period.

C. Phase 3: Develop membership functions

The fuzzy membership functions are used to develop membership functions for each performance metric. The basic definitions of fuzzy sets theory are given by Bojadziev and Bojadziev [13].

Definition 1: A fuzzy set A is defined by a set of ordered pairs,

$$A = \{(x, \mu_A(x)) \mid x \in A, \mu_A(x) \in [0, 1]\} \tag{1}$$

Where $\mu_A(x)$ is a function called membership function; $\mu_A(x)$ specifies the grade or degree to which any element (x) in A belongs to the fuzzy set A.

Definition 2: A membership function of a triangular fuzzy number is defined as follows:

$$\mu_F(X_i) = \begin{cases} 1, \; if\; X_i \leq a \\ 1 - [(X_i - a) / (b - a)], \; if\; a < X_i < b \\ 0, \; if\; X_i \geq b \end{cases} \tag{2}$$

This ideology can be used to develop membership function for each performance metric (M_i) by substituting the values of best performing level and worst performing level of each metric for corresponding a and b values respectively. Therefore, (2) can be modified as it reflects membership function of each performance metric as follows:

$$\mu_F(M_i) = \begin{cases} 1, \; if\; M_i \leq a \\ 1 - [(M_i - a) / (b - a)], \; if\; a < M_i < b \\ 0, \; if\; M_i \geq b \end{cases} \tag{3}$$

The point 'a' represents the maximum performance level and when $x = a$, the corresponding membership value (μ_F) is 1 (i.e. when $x = a$, $y = 1$). Similarly, when $x = b$, the membership value is 0 (i.e. when $x = b$, $y = 0$). This means that there is no membership value exists at the lowest performance level.

This membership function should be developed for each performance metric. The next step is to determine membership values for a specific period of time (i.e. monthly). Fig. 5 shows such membership functions developed for two metrics (i.e. 5S and Andon).

D. Phase 4: Obtain degrees of implementation

The next step is to obtain degrees for each corresponding monthly performance data. These values can be obtained by substituting 'x' value of the membership function with corresponding performance data. The 'y' value indicates the degree of implementation of a particular lean attribute within the system for a given period.

E. Phase 5: Identify interrelationships among lean attributes

The correlations of each lean attribute can be calculated using their degrees. Each lean attribute has been tested with all other attributes to identify correlations. Out of 650 correlations most probable (considering 95% confidence level) correlations are identified. Fig. 6 demonstrates the most probable 23 correlations exist among lean attributes.

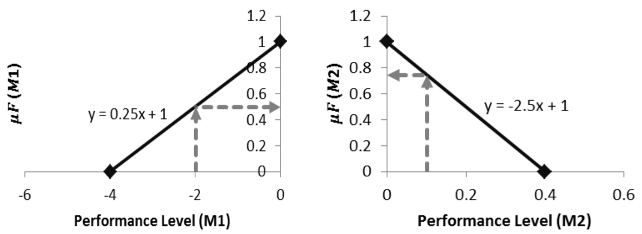


Fig. 5. Membership functions for 5S (left) and Andon (right)

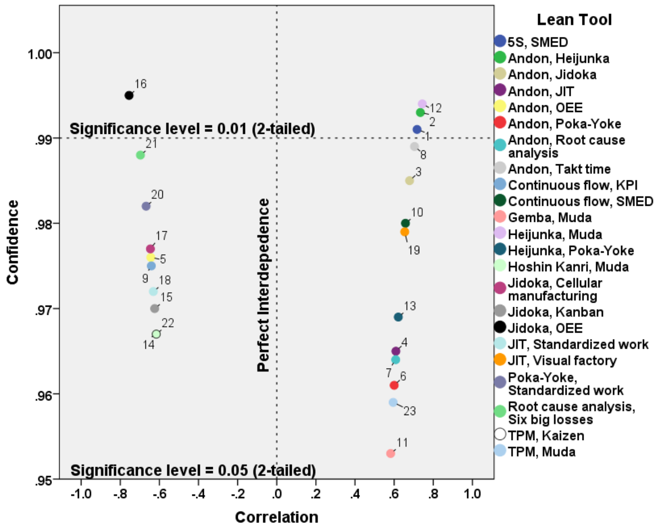


Fig. 6. Correlations among lean attributes

Table 6 provides a summary (sample) of correlations that the research was able to determine.

IV. Conclusion

The first objective was to identify a proxy company. The step 3 found out four companies which are relatively similar to SL subsidiary. The hypothesis test conducted for these companies showed that they were more than 80% similar to SL subsidiary. This indicated that when the companies have similar manufacturing systems they are likely to be similar in terms of leanness as well. Moreover, the step 5 showed that the two lean enterprises selected were more than 91% similar to SL subsidiary in terms of lean culture. This implied that similar lean enterprises also have similar lean cultures.

The second objective was to measure the degree to which lean attributes are implemented in the factory. At phase 3, the membership functions were developed based on best performing level and the worst performing level. The performance levels of each attribute should lie within the scope of benchmarked scale to have a membership value (degree of implementation). Otherwise, the membership value was considered zero for the particular period.

TABLE VI. Correlations Among Lean Attributes

Lean attribute	Correlation	Significance	Confidence
5S, SMED	0.717	0.009	0.99
Andon, Heijunka	0.734	0.007	0.99
Andon, Jidoka	0.679	0.015	0.99
Andon, JIT	0.609	0.035	0.97
Andon, OEE	-0.644	0.024	0.98
Andon, Poka-Yoke	0.6	0.039	0.96
Andon, Root cause analysis	0.608	0.036	0.96
Andon, Takt time	0.704	0.011	0.99

The final objective of the study was to identify possible correlations among lean attributes. Andon (availability of visual feedback in the plant which indicates production status, alerts when assistance required, and authority given for operators to stop production) was positively correlated with several other lean attributes. This indicates that the concept of visual factory is central to other lean attributes. However, it is negatively correlated with Overall Equipment Efficiency. This can be due to conflicting types of objectives of the two attributes or the performance metrics identified may not be the ideal metrics to evaluate the lean attributes. Such incidents should be reviewed by altering metrics in such a way that they describe attributes up to the best possible level. This type of identification of relationships will enable an organization to determine the right choice of lean attributes. Moreover, the benchmarked scale enables the company to compare performance and identify areas require further improvements.

The study was based on the ability of performance metrics to measure the performance of lean attributes. Therefore, selecting metrics and finding required data consume more time and also may influence on the accuracy of results. This opens pathways to lead future research towards developing qualitative relationships among these lean attributes.

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