Using Data analytics to explore opportunities of Lean assessments

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***Abstract*—The suitability of statistical analysis of Lean maturity assessments to generate business value is reviewed. A case study is conducted on a large supply chain company. The relationship between the Lean maturity assessment scores and business performance is explored using Fisher's exact test. The effect size was also reviewed using Cramer's V. The insights of the analysis were shown to the company. They used the results to fund further investment in Lean in the business. The results demonstrated that Lean assessment data can be used for analytics to generate business value. The research provides a new perspective on the Lean qualitative measures and opportunities from statistical analysis.**

Keywords—Lean, Process Improvements, Maturity assessments, Data Analytics

I. Introduction

Lean manufacturing is a process improvement framework that is commonly used in supply chains to increase business performance. Assessments are the most common way to measure implementation success of the improvement framework. These assessments generate a lot of data. At the same time, organisations are becoming more digital with a bigger focus on data analytics. Process improvement assessment can be a new source of data for analysis to understand past events and understand what should be done in the future.

This study aims to investigate if the data generated from the assessments can be used for further analytics and generate useful business insights. Specifically, the value of the data for descriptive analytics is reviewed using a case study in a large supply chain organisation. A relationship between maturity of Lean and the business performance is investigated using statistical analysis. At the same time, the magnitude of the impact is also reviewed. The insights of the analysis are shown to the company to understand if the data analysis provided business value.

II. Existing Theories & Previous Work

Lean manufacturing is one of the most popular improvement methodologies in the business environment [1]. It is focused on adding value to business customers and removing waste in production activities. "Value" can be anything in production that the customer is happy to pay for. Lean has multiple tools and techniques at its disposal. Some of the most famous ones are Kanban, Kaizen, 5S, Just-in-time, Total productive maintenance, Value Stream Maps. It is considered the next advancement in manufacturing after Henry Ford's development of mass-production principles. While the origins of Lean are from the Toyota Production System (TPS) in the 1930s-1960s, the term "Lean" was used only from 1988 [2] [3].

Lean maturity, or "leanness", is an approach to measure implementation of Lean in a business. There are several methods to measure leanness. First approach is quantitative and relies on efficiency metrics. Examples can be Overall Equipment Effectiveness (OEE), Cycle times, Inventory turnover, etc. Second approach is qualitative and relies on assessments, surveys, and questionnaires where responses can be "Yes"/ "No" or a number on a scale from 1 to 5. Examples of questions in assessments can be "Do you manage your bottlenecks?" or "On a scale of 1 to 5, rate how well you manage your bottlenecks". The most common way to measure Lean in a business is through assessments, surveys, and questionnaires [4].

Many sources in the identified literature demonstrated positive effects of lean on the business [5][6][7]. While several publications found a lack of a strong positive relationship between lean and company performance, obstacles in lean implementation were discussed in the studies [8][9]. The key reason Lean can be poorly implemented is if some of the key success factors are not taken into account. For example, there may be poor management involvement, challenging organizational culture or lack of training [10][11][12].

Research about Lean is growing. There are approximately 300 articles published on the subject each year. It is also expected that the count of publications per year will be increasing [13]. With Industry 4.0 and Digitalization being developing subjects in supply chains, a lot of cross-function studies are being published that push Lean into a new, analytics-driven direction [14][15].

Previous studies on comparison of quantitative vs qualitative lean maturity measures exist with defined benefits and drawbacks of each approach that are summarised in Table 1 [16]. It is stated that qualitative measures have a weakness of not being suitable for statistical analysis. This statement can be challenged, as suitability for statistical analysis is defined by data characteristics (data type, sample size, data completeness and accuracy).

TABLE I. Strength and weaknesses of qualitative and quantitative measures of Lean Maturity.

	Qualitative measures	**Quantitative measures**
Strengths	Easy to develop, analyse and administer. Can address wide range of lean aspects.	Objective. Can be done regularly. Can be statistically analysed.
Weaknesses	Subjective. Cannot be statistically analysed. Less informative.	Can be hard to collect. Cannot quantify all types of lean aspects.

In the 2021 study, another process improvement framework was reviewed from data analytics perspective for qualitative measures. An artificial neural network model was developed where inputs of the model were questionnaires to employees. The output of the model was predicting quality of operation [17]. While Lean maturity assessments and TQM questionnaires to employees are different, there is a large overlap. These are both qualitative measures, they are conducted by company employees, and they are part of process improvement frameworks with many similar concepts. The study demonstrated that qualitative assessment can be analysed and can provide business benefits.

This study contributes to previous research by demonstrating additional opportunities of Lean qualitative assessments from the perspective of data analytics. Specifically, a statistical analysis will be conducted on the data from Lean maturity assessments of a large supply chain organisation. The insights value will be judged by company leadership for the existence of business value.

III. Methods

A. Research question & Hypotheses

The research question is: "Can Lean maturity assessments data be statistically analysed to provide business benefits?". To address the question, maturity assessment data of a large supply chain company was analysed, and the findings were presented to the business.

First hypothesis is stated as "Does passing Lean maturity assessment have an impact on business performance?". After the hypothesis is tested, the effect size is also reviewed. The aim of analysis is to find if an organisation's approach in Lean has a positive result on the business performance. If the results show that Lean has an impact on business performance, this aligns with previous literature for the subject. The effect size shows the magnitude of the impact.

If the results show no statistically significant impact, then it is possible that the organisation is not applying Lean correctly or it is not measuring its maturity correctly. Key possible reasons are available in studies that are mentioned in the literature section.

After the overall impact of the Lean framework is analysed, separate sections of the assessments can be reviewed. Hypotheses have the following format: "Does passing section X of Lean maturity assessment have an impact on business performance?". As before, the effect size is also reviewed. The company will have insights which sections have statistically significant impact on the business, and the magnitude of the impact.

New insight can help the business to answer following questions:

- Does the Lean framework help the business?
- How big is the impact of the Lean framework?
- What sections of the Lean maturity help the business?
- How big is the impact of each section of the framework?

In summary, data from Lean maturity assessment are analysed to understand if useful insights can be generated for the business. Firstly, the overall impact of the assessment on the business performance is reviewed. The results can show if Lean is having a positive impact on the business performance, and if it is applied correctly. Secondly, separate sections of the assessment are reviewed. After that, an organisation is able to see which parts of the assessments generate value and which parts have little or no effect on the business.

B. Research methodology

The research methodology involved several steps. First, the data needs to be collected, explored, and cleaned. Examples of issues that were faced are: incomplete assessments and duplicate assessments.

Secondly, the data type is reviewed to define the hypotheses tests. Business performance of teams with high maturity scores is compared against other teams. The size of the effect is reviewed too.

After that, the different parts of assessments are analysed in a similar manner to the previous step. Business performance for each section of assessment is reviewed. The size of the effect of each section is reviewed too.

Finally, the results of the tests are collated and presented to the business. The first part of the feedback demonstrates if the Lean framework is helping the business and what is the effect size. Second part of the feedback shows which elements of the Lean framework are providing value and which elements have no impact on the business. The third, final part of the feedback contains suggestions for improvement based on insights from statistical analysis.

IV. Findings

A. Collected data

A large supply chain company with more than 10,000 employees was chosen for an archival study. The data of 154 teams across multiple regions was collected and analysed. The teams were using the Lean maturity self-assessments for 7 years and there were 6,120 assessments in total with clean data. All assessments for all teams had identical Lean maturity questions and business targets. The assessment records contained multiple Lean maturity questions with "Yes" or "No" responses. The maturity questions were grouped into 20 sections. For example, sections were "Values Stream Mapping", "5S", "Bottleneck management".

The business leadership demands that teams need to pass all Lean sections of the assessments. The reason behind the demand is due to the simplicity of the Lean framework requirements. Business leadership believe they are easy enough for any team to meet. 18.8% of assessments fully meet all the Lean requirements.

During the maturity assessment, teams were recording if they met business targets across key business performance metrics. The business leadership also demands that teams need to meet all these metrics as they are deemed essential for normal operations of the organisation.

For the first hypothesis, the data from maturity assessments was presented in a contingency table shown in Table II based on business leadership requirements of Lean maturity assessments and business metrics.

TABLE II. CONTINGENCY TABLE FOR THE FIRST HYPOTHESIS.

	Lean maturity assessment passed	Lean maturity assessment failed
All key business metrics met	228	567
Not all key business metrics met	924	4401

To compare two categorical variables Chi-squared test or Fisher's exact test could have been used. Due to a large sample, Chi-squared test could have given similar results to Fisher's exact test but with less computational power involved. With modern software and hardware, the computational power for the specific test was not a challenge, so Fisher's exact test was used to get exact accuracy. The Fisher's exact test has following assumptions, and they were all met:

- The row and column totals are fixed.
- Observations are independent.
- Each observation is mutually exclusive.

The null hypothesis in Fisher's exact test is that key business metrics pass rate is not different when Lean maturity assessment passed or not passed. The p-value threshold of significance was chosen to be 0.01. Using scipy Python library, the p-value was calculated as $p<0.001$, so Lean maturity pass rate and business metrics pass rate have a statistically significant relationship.

To understand the magnitude of the effect, Cramer's V was used. The measure represents association between two categories and has value between 0 and 1. The higher the Cramer's V, the higher the magnitude of the effect. The values from Table II gave Cramer's V value of 0.10. It can be interpreted that association exists, but it is low. The low value can be explained that the company Lean framework or maturity assessments need major improvements. Alternatively, it can be explained that there are many internal and external variables that impact business performance. Lean has an impact, but it is not a major influencer.

The next step of the research was to investigate the statistical significance & magnitude of the business impact for each section of the maturity framework. To do so, the data for each section was presented in the contingency table using the format shown in Table III.

TABLE III. CONTINGENCY TABLE FORMAT FOR THE SECOND SET OF HYPOTHESES.

	Lean maturity assessment section passed	Lean maturity assessment section failed
All key business metrics met	Count of assessments	Count of assessments
Not all key business metrics met	Count of assessments	Count of assessments

Fisher's exact test and Cramer's V were used for each section of the maturity assessment. The data is summarised in Table IV. Only 16 out of 20 sections have a statistically significant impact on business performance. Moreover, only 2 sections have a small effect size, while all others are negligible.

TABLE IV. RESULTS TABLE FOR THE SECOND SET OF HYPOTHESES.

Section number	Statistically significant?	Cramer's V value	Effect characterization
1	No	0.03	Negligible
2	Yes	0.04	Negligible
3	Yes	0.04	Negligible
4	Yes	0.06	Negligible
5	Yes	0.09	Negligible
6	Yes	0.05	Negligible
7	Yes	0.08	Negligible
8	Yes	0.04	Negligible
9	Yes	0.08	Negligible
10	No	0.00	Negligible
11	Yes	0.08	Negligible
12	Yes	0.05	Negligible
13	Yes	0.11	Small
14	Yes	0.13	Small
15	Yes	0.05	Negligible
16	Yes	0.04	Negligible
17	Yes	0.06	Negligible
18	No	0.03	Negligible
19	Yes	0.05	Negligible
20	No	0.02	Negligible

B. Discussions

Based on the results, it was shown that the Lean framework and its elements do have a positive impact on the business performance. At the same time, the effect size is low, so there is a possibility to increase it by improving Lean or improving Lean maturity measures.

To improve Lean framework, the business can review effect sizes of the framework elements. 4 sections have no statistically significant impact. The organisation can either remove these sections or they need a significant rework. 14 sections have a statistically significant impact, but negligible effect size. The company can investigate to improve them or consolidate them. Two sections have low effect, so the business needs to review it and understand why they are more successful than other sections. The lessons learned can be applied to improving other sections.

To improve Lean maturity measures, the business needs to address the subjectivity of the maturity assessments. Currently, the data is collected as a self-assessment that can be highly subjective. If the company still wants to use assessments for maturity measures, they can have more assessments completed by trained professionals in Lean. Alternatively, the assessments can be completed by one team assessing other teams' maturity on a rotating basis. For example, Team A is assessing Team B, Team B is assessing Team C, and Team C is assessing Team A. The assessments will still be subjective, but the level of subjectivity can be reduced to have more accurate measures.

The results and suggestions were passed on to the Lean framework owners in the company. They found the insights valuable to decide the future of Lean in their organization. Based on the insights that the framework provides the value to the company and the impact can be further improved, the company leadership decided to invest further in Lean and update the framework and the maturity assessments.

V. Conclusions

A. Limitations & future work

There are two limitations in the current study that will be addressed in the future work. Firstly, the study was conducted only in a single company. While the organization is large and operates across multiple regions, a larger sample of companies is needed to verify the results. More companies will be contacted to conduct similar studies.

Secondly, only descriptive analytics potential of assessment data was explored. Future studies can investigate opportunities in predictive and prescriptive analytics. For example, it can be reviewed if maturity assessment data can improve accuracy of the business forecasts. To do this, a univariate forecast can be compared with a multivariate forecast that includes assessment data.

B. Concluding Remarks

The initial research question was stated as: "Can Lean maturity assessments data be statistically analysed to provide business benefits?". The findings of the case study on the large supply chain company demonstrated that useful insights can be found. Using statistical analysis, it was shown that teams with high scores in Lean maturity assessments have better business performance. At the same time, the effect size of the overall framework is low, and effect size of its elements is in a range from negligible to low. The conclusion of the analysis was that the Lean framework does have a positive impact on the business, but there is an opportunity for improvement. The company has taken the feedback and found the insights valuable. They decided to further invest in Lean. Based on these events, the response to the initial question is positive: data from maturity assessments can be statistically analysed and it provides business benefits. The new knowledge contributes to the field of Process Improvement. It is highlighting that maturity assessments need to be statistically analysed and insights can provide value to the business users.

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