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Development of a modeling algorithm to predict lean implementation success

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DEVELOPMENT OF A MODELING ALGORITHM TO PREDICT LEAN

IMPLEMENTATION SUCCESS

by

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ABSTRACT

Lean has become a common term and goal in organizations throughout the world. The approach of eliminating waste and continuous improvement may seem simple on the surface but can be more complex when it comes to implementation. Some firms implement lean with great success, getting complete organizational buy-in and realizing the efficiencies foundational to lean. Other organizations struggle to implement lean. Never able to get the buy-in or traction needed to really institute the sort of cultural change that is often needed to implement change. It would be beneficial to have a tool that organizations could use to assess their ability to implement lean, the degree to which they have implemented lean, and what specific areas they should focus on to improve their readiness or implementation level.

This research investigates and proposes two methods for assessing lean implementation. The first is utilizing standard statistical regression. A regression model was developed that can be used to assess the implementation of lean within an organization. The second method is based in artificial intelligence. It utilizes an unsupervised learning algorithm to develop a training set corresponding to low, medium, and high implementation. This training set could then be used along with a supervised learning algorithm to dynamically monitor an organizations readiness or implementation level and make recommendations on areas to focus on to improve implementation success.

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Sincerely, from the bottom of my heart, thank you!

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1. INTRODUCTION

Lean manufacturing has become interwoven into the fabric of many of the world's leading manufacturing organizations. Lean has also taken hold in other industries such as services and health care. The term lean has become so commonplace that it has almost become generic in its use and meaning among some organizations. As the world welcomes the dawn of the next industrial revolution, organizations must constantly seek to stay on the forefront or risk getting left behind. For many organizations this may still mean fully adapting a lean culture that values waste elimination and continuous improvement. For other organizations this may mean finding new ways to monitor their organization and the lean culture in general. This research aims to help organizations do both of those things.

The first paper presented is a thorough literature review of using structural equation modeling to identify factors critical for successful implementation of lean. The literature review identified 32 unique factors that had been found to be critical for lean implementation.

In the second paper, two main objectives were accomplished. The first being the identification of the most relevant factors affecting lean implementation. Secondly and, perhaps more importantly, the development of a comprehensive framework for the relationship between various organizational and cultural factors with lean implementation. This framework was established in the form of a regression model which inherently is a predictive model. This model can be used by organizations to predict whether their organization is ready for lean implementation.

The third, and final paper, was focused on utilizing artificial intelligence to help organizations utilize internal data streams to identify and take action on areas of concern throughout a lean organization or an organization looking to implement lean. This research utilized unsupervised learning to generate clusters representing low, medium, and high degrees of lean implementation relative to organizational and cultural data points. This research provides a dataset that could be used as a training set for a supervised learning algorithm that could be deployed in an organization to help drive continuous improvement from an organizational culture standpoint, relative to lean implementation.

The original contribution of this work is twofold. First, the predictive regression model can be utilized by organizations looking to assess their readiness to implement lean. Secondly, a novel approach to real-time organizational monitoring of lean implementation was proposed and the training set needed to execute the supervised learning algorithm was developed.

PAPER

I. STRUCTURAL EQUATION MODELING IN LEAN PRACTICES: A SYSTEMATIC LITERATURE REVIEW

ABSTRACT

The industrial revolution brought great change to the world. The creation of factories, mass production, and the moving assembly line helped fuel growth of economies across the world. New products and conveniences were introduced to the masses and created incredible opportunity in existing and new markets. These opportunities generated incredible revenue and where there is great revenue, there will inevitably be competition. Over the past forty or fifty years companies have sought to increase their competitive advantage by decreasing their costs while improving productivity and quality to create more value for their customers and stakeholders. Many companies have turned to lean in order to accomplish this. While many companies have been successful in implementing lean within their organizations, others have not. In order to understand what enables companies to implement lean successfully a literature review was performed to study what factors have been identified as key drivers of a successful implementation. Further, this study looks to identify what factors have been identified using structural equation modeling (SEM) as the primary modeling method. SEM is well suited for this type of modeling as it allows researchers to propose a model and use SEM to validate the model constructs and validity. A systematic literature review was conducted to identify the research conducted which utilized SEM to identify the critical

success factors for lean implementation and the impact of lean implementation on business results. This review presents thirty two unique factors presented in forty one papers representing over 24 countries.

1. INTRODUCTION

The concept of lean is not new (Womack and Jones 1990, Kajdan 2008). What began as the Toyota production system (TPS) many decades ago has since transformed into the lean culture that many companies consider to be paramount to the foundation of their success. What began as a way to improve manufacturing efficiencies, reduce manufacturing flow times, and drive down quality defects has since morphed into an enterprise level approach to doing business. No longer are top-tier companies concerning themselves only with the singular focus of a lean manufacturing line. Today those who seek to truly achieve world class operations are finding it necessary to take a holistic approach to lean and drive towards an enterprise culture that values the principles of lean at all levels. This lean enterprise approach has the ability to drive the same efficiencies once reserved for manufacturing through all areas of the business and across all industries including healthcare and service, amongst others. The ability to eliminate waste, drive efficiencies, mistake proof, improve first pass quality, etc. is now being regarded as critical for all aspects of business.

Although the leaders of most companies understand the benefit of a lean enterprise, the ability to enact the change required to truly shift to this approach has been troublesome for many. In the US, there is a deep set culture throughout the manufacturing industry that tends to associate change with management directed initiatives that cycle in and out of fashion as leadership changes or turns over. This "flavor of the month" view can be detrimental to an organization when trying to enact a shift towards lean thinking. Additionally, many may view lean as an attempt to reduce head count, a leaning out of the workforce so-to-speak, that causes negative views and pre-conceived notions which can inhibit an organizations ability to succeed. These issues and others can contribute to an environment where employees are not ready or willing to internalize the fundamental principles necessary for a successful transformation to a lean enterprise. No matter how many posters, presentations, slogans, or consultants, if the employees responsible for the day-to-day activities of the business are not committed to and invested in the change, success will be hard to come by.

As more companies begin on the journey to enact this change they likely will do so without a solid, fundamental understanding of the state of their employees as it relates to their willingness to accept change. In these companies specifically, it would be of great benefit to be able to assess the climate of the employees as it relates to their willingness to accept an enterprise shift towards lean thinking. If leaders had a way to gather specific information from their employees and interpret it in such a way that they could reliably determine whether or not the employees, as a whole, would be open, willing, and invested in the lean enterprise philosophy before attempting to shift their company in that direction, the success rate of implementation could potentially be greatly improved. Additionally, this information could potentially be used to focus attention on improving areas that might prevent a successful transformation to lean.

While literature exists that attempts to identify the critical success factors, much of the literature is qualitative or limited in scope. Quantitative methods such as structural equation modeling (SEM) can be used to determine the impact of factors on lean implementation success. SEM utilizes observed or measured variables (MVs) and unobserved or latent variables (LVs). LVs are hypothetical constructs which cannot be measured directly but can be represented in terms of MVs. In other words, SEM is a modeling technique to specify, estimate, and evaluate models of linear relationships among a set of MVs in terms of a generally smaller number of LVs (Shah & Goldstein, 2005). In many modeling techniques the goal is to develop a model based on the available data. When employing SEM a model is developed first and the data is used to determine the validity of the proposed model. Therefore, the scope of this systematic literature review is on the use of SEM to identify the factors that are critical in lean implementation.

To fill this gap in the existing published research, this literature review will investigate the research that has been conducted on determining the critical success factors for lean implementation in various industries across the globe. The aim is to review the existing literature on the use of SEM in identifying critical success factors, provide a better understanding of how SEM can be used to improve lean implementation, recognize differences in applications, identify challenges and limitations of SEM, and provide principal findings.

1.1. SYSTEMATIC LITERATURE REVIEW METHODOLOGY

The purpose of this review is to study the existing literature on utilizing SEM to identify factors which are critical to successful implementation of lean. A thorough search and review was performed on peer reviewed literature and a detailed analysis and summary was prepared on all relevant articles. The main goal of this review was to assess the findings related to the topic and identify any gaps and potential areas for exploration. The review followed the systematic review methodology discussed by Tranfield et al. (2003), which identified three stages in the systematic review process:

Stage 1: Planning the Review

Stage 2: Conducting the Review

Stage 3: Reporting and Dissemination

In planning the review a general framework was set to establish the goal of the review and the specific actions needed to realize the goal. The actions identified to complete the review are provided in Figure 1.

1.1.1. Action 1 - Determine the Goal of the Paper. The goal of the paper was to assess the current state of research into utilizing SEM to identify critical success factors (CSFs) for lean implementation.

1.1.2. Action 2 - Determine the Relevant Databases to Search and the Order in Which to Search Them. The following databases were identified and the search order established:

- ABI/Inform: Covering approximately 1,000 business journals worldwide, ABI/Inform was selected to gain coverage to popular business journals from around the globe.

- Web of Science: Covering nearly 21,000 journals in science, engineering, social sciences and humanities, Web of Science was included to capture articles written in engineering and psychology journals.
- SCOPUS: As the world's largest abstract and citation database of peer-reviewed literature, SCOPUS was selected due to the deep repository of scientific and technical journals.

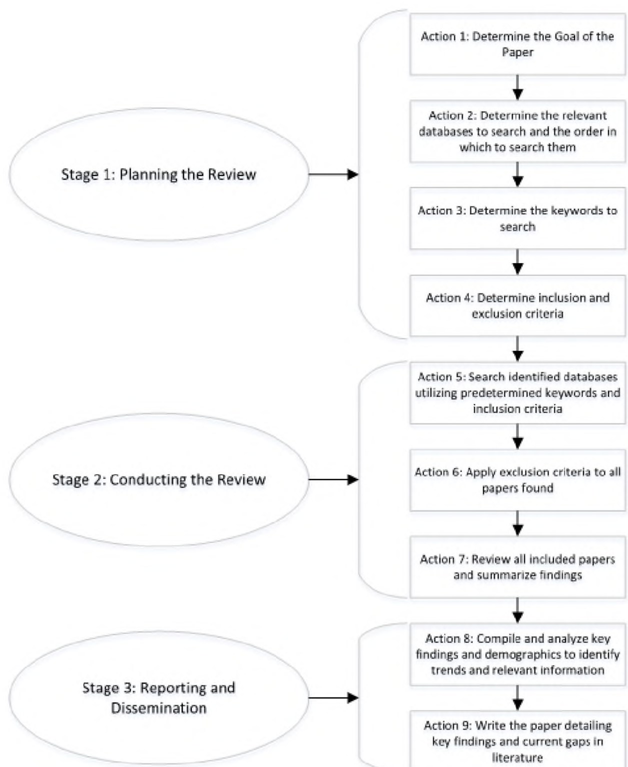

Figure 1. Systematic review framework

1.1.3. Action 3 - Determine the Keywords to Search. Based on the goal of reviewing articles related to SEM in regard to lean implementation the keyword search criteria utilized were "Lean" and "structural equation modeling". This allowed for a broad range of papers across multiple industries with different specific focus, while still providing valuable information related to the goal of this review.

1.1.4. Action 4 - Determine Inclusion and Exclusion Criteria. The inclusion criteria included peer reviewed, journal articles written in English. Additional exclusion criteria was identified. Papers were excluded if there was no mention of lean implementation or SEM in the abstract. Paper were also excluded if they were already obtained in a previous database (a duplicate article). Stage 2 of the review included actions 5-8. These actions are summarized next. The search was not limited to a specific industry, size of organization, or geographic location.

1.1.5. Action 5 - Search Identified Databases Utilizing Predetermined Keywords and Inclusion Criteria. The databases identified in action 2 were then searched based on the keywords in action 3. Papers were included based the criteria established in action 4. The results of databases searched included 141 papers.

1.1.6. Action 6 - Apply Exclusion Criteria to All Papers Found. The databases were searched in order and exclusion criteria applied. The results are summarized in Table 1.

Table 1. Summary of literature review search

Database	**Papers Identified**	**Duplicate Papers**	**Excluded Papers**	**Included Papers**
ABI/Inform	17	0	7	10
Web of Science	29	6	12	17
SCOPUS	95	31	81	14
Total	141	36	99	41

2. LITERATURE REVIEW ON STRUCTURAL EQUATION MODELING IN LEAN IMPLEMENTATION

As organizations across the globe have sought to increase their competitive advantage and drive value for their customers lean manufacturing has become a mechanism many firms have used to position themselves for success. The ability to model and analyze an organization's ability to implement lean would potentially be a valuable tool and while there are several modeling strategies that one could employ to attempt to achieve this, SEM seems particularly well suited.

This review was conducted according to the criteria detailed in the systematic literature review section. During the review process two distinct classification of papers were identified, which include 1) papers applying SEM to identify the factors that are critical for the successful implementation of lean; and 2) papers employing SEM to identify the impact of lean implementation on business results. The following section details the review of studies utilizing SEM to identify CSFs for lean implementation.

2.1. APPLICATION OF SEM TO IDENTIFY CSFs FOR LEAN IMPLEMENTATION

During the systematic review, the majority of the peer reviewed journal papers applied SEM in order to identify the CSFs for lean implementations. In addition, several of these papers applied SEM with additional methods such as confirmatory factor analysis (CFA) and exploratory factor analysis (EFA). Summaries of these papers are provided next in chronological order. Cua et al. (2006) investigated the relationship between total quality management (TQM), just-in-time (JIT), and total productive maintenance (TPM) to determine how the implementation of these three components affected overall lean implementation. Confirmatory factor analysis (CFA) was used to model the fit as covariation. The research was based on results from the 1997 world class manufacturing (WCM) survey conducted by researchers at several universities around the world and consisted of manufacturing companies from Germany, Japan, Italy, United Kingdom, and the United States. The SEM determined that there was high correlation between the simultaneous implementation of all three aspects of Lean and successful implementation. The results indicated that a piecemeal approach to implementation reduced the effectiveness and results of the implementation.

Vinodh and Joy (2012) focused on utilizing SEM to evaluate critical success factors for a successful lean implementation in small and medium enterprises (SMEs) in India. Survey responses from 50 SMEs were utilized for the modeling. SEM indicated that there were correlations between the 10 proposed constructs which included management responsibility leanness and manufacturing management leanness; management responsibility leanness and manufacturing strategy leanness; management responsibility leanness, technology and workforce leanness; management responsibility leanness and organizational performance; manufacturing management leanness and manufacturing strategy leanness; manufacturing management leanness, technology and workforce leanness; manufacturing management leanness and organizational performance; manufacturing strategy leanness, technology and workforce leanness; manufacturing strategy leanness and organizational performance; and technology and workforce leanness and organizational performance.

Nahm et al. (2012) surveyed 180 production workers located in the Midwestern United States to gain insights into employees perceived job security and how it related to successful implementation of lean. CFA was used in conjunction with SEM to create a structural model. The model showed that perceived job security was positively correlated to personal trust in management which was positively correlated with perceived personal benefits of lean implementation, which was positively correlated with lean implementation success. Additionally, training in lean concepts and techniques was positively correlated to both perceived benefits of lean implementation and lean implementation success. The research also sought to identify differences based on firm size. Firms were broken up into three categories; small firms (less than 100 employees), medium firms (100-249 employees), and large firms (250 or greater employees). The work identified that personal trust in management affecting perceived benefits of lean implantation was not supported in large firms. Additionally, perceived job security affecting personal trust in management was significant but lowest in large firms. Further, training in lean concepts and techniques was more highly correlated with perceived personal benefits of lean implementation in large firms. The authors suggested these results may be due to the decreased concern of job security that may accompany employment at a large firm and the need to achieve personal benefits from training in large firms.

Habidin and Yusof (2013) evaluated 252 Malaysian automotive companies to construct their model. The research focused on determining the critical success factors for Lean Six Sigma implementation in Malaysian automotive companies. The research was based on a survey constructed using a 7 point Likert scale. The seven constructs that the researchers evaluated were leadership, structured improvement procedure, quality information and analysis, supplier relationship, JIT, customer focus, and focus in metric. Exploratory factor analysis (EFA) with varimax rotation was performed and Kaiser-Meyer-Olkin was used to measure sampling adequacy. CFA was used to confirm the fit of the model. The two factors the research found to be most important were leadership and customer focus.

The work of Yang and Yang (2013) focused on incorporating the hard aspects of the TPS (just in time, pull systems, etc.) with the soft side (human resource management [HRM], TQM, and people skills). The research employed SEM to model the causal relationships between the factors. The work related the people skills aspect to Maslow’s need theory and Herzberg’s two factor theory. The SEM model was constructed based on responses from a survey distributed to 620 Taiwanese manufacturing firms. From the distributed surveys 169 responses were received, of which 153 were considered valid for the work. The results of the SEM indicated that the main driver for lean success was people factors (Maslow’s Theory and Herzberg’s Theory). People factors either directly, or indirectly, drove the rest of the variables investigated, with no other variable having any significant effect. Additionally, there was two way significant effect between HRM and continuous improvement (CI), TQM and CI, JIT and CI, performance and autonomation, and a direct significant effect from CI on autonomation.

Ravikumar et al. (2013) studied the CSFs for implementing lean in Indian manufacturing companies. SEM was employed to identify and rank the factors. The model identified financial capabilities as the primary driver of successful lean implementation. The remaining factors identified as being critical are commitment of top management, change in organization belief and culture, linking improvement initiatives to business strategy and cost, knowledge sharing, continual evaluation, effective leadership, comprehensive education and training, employee involvement, facilitator sensei, and willingness to learn.

Sangwan et al. (2014) utilized a survey to identify lean implementation drivers in the Indian ceramic industry. The research utilized EFA, CFA, and SEM to propose and validate the model. Twelve drivers were identified. The research identified eight papers from which to draw their baseline drivers. Through their discussions with industrial experts, an additional driver was determined - the unavailability of skilled workers. Further, through discussions it was found that senior managers felt lean would decrease the number of skilled workers required and would also decrease the level of skill needed by the workers, which was a motivating factor to pursue lean. The model determined six major areas contributing to lean implementation including supplier development for JIT deliveries, customer engagement early on, process control, process flexibility, employee training and education, and 5S and standardization.

Jayamaha et al. (2014) utilized data collected by Toyota Knowledge Center through internal surveys to model the relationships between CI and people development (PD), Toyota way (TW) deployment with CI, and TW deployment with PD. Specifically, three hypotheses were developed and tested, which include (1) process improvement (response) is caused by people development (predictor); (2) TW deployment (response) is caused by process improvement (predictor); and (3) TW deployment (response) is caused by people development (predictor). SEM was used to test these hypotheses with the first hypotheses being supported while the third was not. The findings of the research indicated that the relationship between people development and TW deployment is fully mediated by process improvement.

The work of Chavez et al. (2015) was focused on understanding the link between upstream and downstream supplier relationships on internal lean performance (ILP), ILP on company performance, and technological turbulence (TT) on the link between ILP and company performance. The data was collected via a survey distributed to manufacturing companies in Ireland. SEM was used to validate the proposed relationships and the results indicated that supplier partnership had a direct effect of ILP, customer relationship had a direct effect on ILP, ILP had a direct effect on operational performance, and ILP had a direct effect on organizational performance.

Dubey and Singh (2015), utilizing a systematic literature review, investigated the use of interpretive structural modeling (ISM) and fuzzy MICMAC (Matriced' Impacts Croisés Multiplication Appliquée á un Classement) to determine the link between variables related to lean manufacturing in Indian manufacturing firms. The key variables identified in the literature review were just-in-time, lean behavior, TQM, business performance, top management support, team work, real-time production information, training, and customer demand. The ISM determined that top management commitment was the base of successful lean implementation. Driving power analysis was performed that showed top management support, training, real-time production environment, and training to be high drivers with low dependency on other drivers, meaning that these items should be considered crucial to driving a successful implementation.

The work of Shah et al. (2015) pointed to management failure to implement quality practices and disinterest of employees as reasons why quality initiatives such as lean fail to be fully implemented. The research sought to develop a lean model of quality improvement following traditional TQM philosophies. The model factors were developed using EFA and CFA. The relationships of the factors were then established utilizing SEM. The research identified four critical success factors for a lean quality improvement model, which included organization size and structure; organizational culture; organizational behavior toward quality; and measurement and analysis. The researchers validated their model through expert opinion. Five experts in the field of software quality were interviewed and asked to rate different aspects of the model using a standard Likert scale. Overall, the experts agreed with the model.

The work of Noori (2015a; 2015b) focused on identifying CSFs for lean implementation in hospitals located in Tehran, Iran. Path analysis was utilized as part of the SEM approach to determine several CSFs that had a high positive correlation with lean success. Management system was found to have the highest correlation (0.94) with lean success. Management system included the variables performance evaluation, communication, management involvement, responsibility, and commitment. Strategic management system, shared vision, and clear sense of lean outcomes were all grouped together as strategic orientation, which had a correlation of 0.77. Implementation process and implementation team both had correlation of 0.69, while organizational culture had a correlation of 0.5. Organizational culture consisted of the effect of quick wins, need and belief about ongoing improvement, and aim for change.

The research of Al-Hyari et al. (2016) makes the assumption that lean “bundles” (e.g., JIT, TQM, HRM) must all be implemented in order to gain the full benefit due to synergistic effects. The researchers point to studies that claim larger organizations have more success implementing lean. The research involved performing a survey using a 5 point Likert scale. Convergent and discriminate validity were both assessed using a CFA model and the model fit indices were acceptable. The model fits the assumption that the bundles should not be implemented individually and that all bundles positively impact performance. However, the proposed model did not support the claim that larger organizations had easier implementations due to greater resources. Further, the study found that effective leadership at top and bottom levels of the company are necessary to eliminate roadblocks.

Ravikumar et al. (2016) evaluated the effect of financial constraints on lean implementation in six Indian micro, small, and medium enterprises (MSMEs). Utilizing SEM the work showed the following factors all had strong positive correlation with lean implementation, with the factors listed with the highest weighting first: strong management leadership, resistance to change, employee trust, skills and expertise, financial capabilities, communication of the transformation process and objectives, performance measures, education and training, plan and strategy, thinking development, and customer focus. The factor weights were then used in TOPSIS and fuzzy TOPSIS analysis to rank the six organizations that responded to the survey based on level of implementation according to the model.

van Dun and Wilderom (2016) focused on Schwartz's self-transcendence values cluster because they fit the values ascribed by many authors to effective lean leaders. The research involved six hypotheses including (1) the more lean-team leaders endorse self-transcendence work values, the higher their teams' effectiveness; (2) the more lean-team leaders endorse conservation work values, the lower their teams' effectiveness; (3) lean-team leaders' self-transcendence work values are positively related to their team members' information sharing behavior; (4) the positive relationship between lean-team leaders' self-transcendence work values and team effectiveness is mediated by the degree of information sharing within the team; (5) lean-team leaders' conservation work values are negatively related to their team members' information sharing behavior; and (6) the negative relationship between lean-team leaders' conservation work values and team effectiveness is mediated by the degree of information sharing within the team. The research found that having leaders with self-transcendence work values and teams with high degrees of information sharing had a strong positive correlation with team success. Conversely, the study found that leaders with conservational values had a negative impact on success.

Bevilacqua et al. (2016) investigated the benefits of lean manufacturing in relation to operational responsiveness and company growth performance in Italian manufacturing companies. A survey was conducted of Italian manufacturing companies, garnering 254 responses, or approximately 10.5% of the targeted population. The survey results indicated that most of the companies had responses which indicated that they were still in the startup phase of lean, indicating that lean likely had very limited impact on company performance to date. SEM was used to determine that lean implementation was negatively related to product mix variety. Product innovation was not found to be positively related to lean. Time effectiveness was positively associated with lean implementation. Further, the model indicated that there was not a direct relationship between lean implementation best practices and company growth performance; however, there was a direct relationship between product mix variety and growth performance. The model also validated that time effectiveness is directly linked to growth performance. With the model indicating that product mix variety and time effectiveness were positively influencing company growth, a conclusion can be drawn that lean implementation acts as a mediator between time effectiveness and growth performance.

Randhawa and Ahuja (2016) focused their work on what factors lead to successful 5S deployment throughout Indian enterprises, with the idea that successful 5S deployment was a required precursor to follow-on quality initiatives such as lean. SEM was used to determine that top management involvement issues (e.g., communication, resources, strategic plan), Employee involvement issues (e.g., training, skills, motivation, cross-training) and fifth S initiatives (sustaining) were key to successfully deploying 5S and realizing increase in business performance.

Tomic et al. (2017) focused their research on how cultural dimensions affect the impact of quality improvement tools and methodologies and how those ultimately translate to business performance. The research was also interested in how this affected supply chain partners as a whole. Quality improvement tools and methodologies, cultural dimensions, and business performance indicators were all grouped using factor and reliability analysis. Then SEM was used to test the model using data collected from the Canadian aerospace company Bombardier Inc. sites and suppliers worldwide. The model showed that communication in organization, goals and objectives, level of formalization, reward system, and progress and development were the key cultural dimensions that affected quality tools and methodologies. The model also suggested that the quality tools identified (e.g., six sigma, kaizen, lean, corrective action) correlated with business performance indicators.

Paranitharan et al. (2017) were interested in the success factors for an integrated manufacturing business excellence system (IMBES). The system is a bundle of common management practices, including TQM, TPM, corporate social responsibility, knowledge management, lean manufacturing, agile manufacturing, and sustainable manufacturing. Through a literature review, 10 critical success factors were identified and used to build the model. A survey of manufacturing firms in India were used to perform regression analysis. The success factors identified included customer focus and satisfaction, continuous improvement and innovation, organizational culture, visionary leadership and management commitment, systematic approach to management, supplier quality management, workforce management, manufacturing strategy, manufacturing practice audit system, and technology management and information system.

In their literature review, Basu et al. (2017a) supplied many different definitions of lean developed throughout the years. Basu et al (2017b) focused their work on the identification of HR and internal practices and processes that contributed to lean implementation in Indian Manufacturing. The research utilized a Delphi exercise with industry experts along with EFA to help build the constructs for the model. The model tested eight hypotheses related to successful implementation of lean, which included (1) HRM is positively related to successful lean implementation; (2) integrated planning and scheduling is positively related to successful lean implementation; (3) internal operations synchronization is positively related to successful lean implementation; (4) management role is positively related to successful lean implementation; (5) quality governance is positively related to successful lean implementation; (6) strategic process control is positively related to successful lean implementation; (7) successful lean implementation is positively related to organizational goal satisfaction; and (8) successful lean implementation is positively related to customer satisfaction. The research followed the outline provided by Sangwan et al. (2014) to identify, develop, and validate the model using EFA, CFA, and SEM. A survey was used to gather information from manufacturing companies in India with more than 100 employees. A total of 467 usable survey responses were obtained. The model showed that all hypotheses were confirmed and significant with hypothesis 6 being significant at the < 0.05 level while the rest were significant at < 0.01. Although the impact of each proposed driver was similar to the rest, HRM was determined to be slightly more impactful than the rest. HRM included items such as workforce development, training, job rotations, along with having a cross-functional workforce.

Sreedharan et al. (2018) point to a lack of lean six sigma awareness (LSSA) as a reason many companies fail to implement lean six sigma (LSS). Their work focused on understanding LSSA in Indian manufacturing companies. They proposed a set of constructs that could be used to assess LSSA and how it will influence LSS implementation in Indian manufacturing. The four proposed constructs were (1) impact of LSS has a positive influence on top management commitment (TMC); (2) impact of LSS has a positive influence on lean six sigma implementation; (3) acceptance towards LSS has a positive influence on TMC; and (4) acceptance towards LSS has a positive influence on lean six sigma implementation. The findings suggest that TMC is influenced by lower level buy-in, whether it is through the impact the LSS tools make on employees day to day work, or through the acceptance of the training and tools provided to employees. A survey was developed and distributed and EFA and CFA were used along with SEM to test the model's validity. Based on the survey responses the model found the constructs 1, 3, and 4 were significant, while construct 2 was not. The authors suggested that even though the employees may see the positive impact of using LSS tools in their work, without encouragement and direction from leaders there did not seem to be a positive impact on implementation.

Khalili et al. (2018) were interested in utilizing SEM to model the effect of soft total quality management (STQM) on lean manufacturing (LM) in Malaysian manufacturing. Through distribution of a survey to 900 individuals in Malaysian manufacturing companies they were able to receive 329 responses to validate their proposed model. The research was able to show STQM and LM are not in conflict with each other inside an enterprise and do in fact complement each other with STQM being a driver of LM tools and principles.

Ramadas and Satish (2018) utilized SEM to model employee barriers to lean implementation in small and medium enterprises in India. The model utilized data collected through face to face interviews. The study indicated that in order to successfully implement lean in SMEs in India, organizations needed well trained and experienced employees, employee awareness and engagement with lean specialists, and a supportive organizational culture.

2.2. APPLICATION OF SEM TO IDENTIFY THE IMPACT OF LEAN IMPLEMENTATION

In addition to identifying CSFs for lean implementation, several papers were reviewed that utilized SEM to identify how lean impacted business performance, and customer satisfaction, among others. This section summarizes the results of those studies.

Zakuan et al. (2010) studied the link between TQM and organizational performance in Malaysian and Thai automotive suppliers. Nine hypotheses were formulated based upon the literature review which focused on impact of TQM practices on organizational performance in the areas of TQM implementation, quality leadership, customer focus and satisfaction, quality information and analysis, human resource development, strategic planning management, supplier quality management, quality results, and quality assurance. The research utilized a structural equation model to validate the hypotheses; however, the results of the study were not reported.

Jabbour et al. (2012) investigated the relationships between environmental management (EM), operational performance (OP), lean manufacturing (LM), and human resources (HR) in Brazilian automotive companies. The model found that LM had a moderate, positive effect on EM, while EM had a weak effect on OP, both of which were significant at 99%. HR, however, had a weak effect on EM at a significance level of 90%.

Habidin and Yusof (2012) were focused on evaluating the relationship between lean six sigma (LSS) and OP in the Malaysian automotive industry, and in particular how the adherence to, or lack of, ISO 14001 could moderate the effect LSS has on OP. CFA and SEM were used to model the effects of LSS on OP in companies how were certified to ISO 14001 as well as in companies who did not work to ISO 14001 certification. The model showed a modest increase in LSS→OP coefficient when working to ISO 14001 certification.

Qrunfleh and Tarafdar (2013) investigated the relationship between strategic supplier partnership, lean, supply chain responsiveness, and firm performance. Harman's single factor test, EFA, CFA, and SEM using AMOS 7 were utilized to develop the model. A bootstrapping test was used to test for indirect relationships. The model found that the direct effect of lean supply chain strategy on supply chain responsiveness was not statistically significant. It found that the agile supply chain effect on supply chain responsiveness was statistically significant. The model also determined that strategic supplier partnership fully mediates the relationship between lean supply chain and supply chain responsiveness and that postponement partially mediates the relationship between agile and supply chain responsiveness. This research provided a link between lean (agile) supply chain strategy and firm performance.

Hong et al. (2014) investigated the relationship between strategic customer service orientation implemented through lean practices and business performance. The research was grounded in socio-technical systems (STS) theory. The research hypothesized that a competitive marketplace could lead an organization to develop a strategic customer service orientation, which could trigger waste elimination and other lean activities in an effort to increase business performance. The hypotheses were tested using the international manufacturing strategy survey (IMSS) IV, which was conducted in 2005. SEM using analysis of moment structures (AMOS) 20 was utilized to analyze the data. The research found that firm size, geographical differences, and gross domestic product (GDP) per capita affect the implementation level of lean manufacturing practices and performance outcomes. The research also determined that the relationship between competitive market environment (CME) – strategic customer service orientation (SCSO) – operational performance outcomes (OPOs) – business performance (BP) was not statistically significant for small to medium sized firms, while those relationships were significant for large firms. The model also showed that the relationship between CME –

SCSO – HLPs – OPO – BP was not significant for European firms, while it was significant for non-European firms. The research also noted a significant link from human lean practices (HLPs) to OPOs and BPs, and while technical lean practices (TLPs) did not share this same link, it did show a link to HLPs. HLPs were defined as items such as employee empowerment, training, autonomy, and kaizen activities, among others.

García-Alcaraz et al. (2014) focused their research on the effect of JIT production systems on human resources and financial performance in Mexican manufacturing companies. The research considered JIT systems to essentially be equivalent with a Lean system in that it focuses on waste elimination. The work used SEM to determine that JIT had a direct effect on human resources. Human resources had a direct effect on production processes, inventory, and economic performance. Production processes had a direct effect on inventory and economic performance. In addition, inventory had a direct effect on economic performance.

The research of Fullerton et al. (2014) focused on understanding the link between lean thinking and management accounting practices (MAP). The goal of the research was to determine whether management needed to be concerned with implementing lean MAP as part of a holistic lean organization. The research was based on a survey conducted on 244 managers in US based manufacturing firms. EFA and CFA were used along with SEM to identify the relationships. The results indicated that lean manufacturing was positively associated with simplified and strategic management accounting (SMAP), value stream costing (VSC), visual performance measures (VLPM), and operations performance (OPRF). SMAP had a positive effect on VSC. VSC had a positive effect on

VLPM, but no significant effect on OPRF. VLPM had a positive effect on OPRF. And OPRF had a positive effect on financial performance.

Bortolotti et al. (2014) formed their research around the sand cone model of cumulative performance. The research theory was that in order for a company to truly achieve maximum potential in their respective field, the company must first achieve a foundational "fitness"; which was likened to foundational fitness to athletic training. In order for an athlete to be elite, they must have focused training in their specific sport, in addition to that, they must have foundational fitness in areas such as speed, agility, and strength. Without this foundational fitness it would be considerably more difficult for the athlete to excel in their specialized training. The research used data from the third round of the high performance manufacturing (HPM) data set which was collected in 2010. CFA was used along with SEM to determine that quality performance was directly related to delivery performance. Delivery performance was directly related to flexibility performance. Flexibility performance was directly related to cost performance. TQM was directly associated with quality performance. JIT was directly related to quality and delivery performance.

McFadden et al. (2015) investigated the relationship between lean, six sigma, and goal specificity in healthcare. The research was designed to test whether lean had a positive effect on patient safety outcomes, six sigma, and goal specificity, individually. Additionally, a link between six sigma and responsiveness and goal specificity and responsiveness was investigated as well as responsiveness and patient safety outcomes. The model indicated that although lean did not have a direct link to patient safety outcomes, it did have a strong correlation with both six sigma implementation and goal specificity. Further, both six sigma and goal specificity were found to have strong positive correlations to responsiveness which, in turn, had a strong positive correlation to patient safety outcomes.

Habidin et al. (2016) were interested in establishing a link between LSS implementation, strategic control, and OP in Malaysian automotive suppliers. The hypotheses were centered on the idea that strategic control could be used to closely monitor the impact of LSS on OP and could be used to make course corrections along the way, allowing for a more robust and effective implementation. Survey responses were analyzed using SEM with AMOS V6.0 using a six stage, structured framework as recommended by Hair et al. (1998). The study found a strong positive correlation between LSS and OP. However, the effect of SCS on OP and LSS was less clear.

The research of Gholizadeh et al. (2016) focused on determining the effect of lean on hospital performance in Iran. EFA was used along with SEM to determine that communication, human, processes, management, technology, and structural factors all had a direct and significant impact on improved quality through lean implementation.

The research of Dobrzykowski et al. (2016) was focused on modeling the effect of lean methodologies in the healthcare industry and how the implementation of lean affected both patients and financial performance. The work also investigated internal integration, or how well a company communicates, coordinates, and works across functions and how that integration affects lean orientation. CFA was used to examine the variables and relationships. The SEM analysis determined that comprehensive lean orientation had a direct impact on patient safety, but no direct significant impact on net income. The model determined that comprehensive lean orientation was a mediator for net income, through internal integration. Meaning that the direct relationship between lean and integration was significant, and the relationship between integration and net income was significant. Further, testing the indirect effect of lean orientation on net income revealed a positive and significant indirect effect.

The work of Sajan et al. (2017) focused on identifying the relationship between lean manufacturing practices (LMPs) and sustainability performances in Indian SMEs as well as the interrelationship of the sustainability performances (e.g., economic, social, and environmental). Their research refers to their sustainability performances as analogous to the popular triple bottom line (3BL) of people, planet, and profit. Standard SEM methodologies including CFA were utilized on survey results to validate the proposed hypotheses. The model concluded that LMPs enhanced environmental, economic, and social sustainability performances. When looking at the interrelationships of the sustainability performances, the model indicated strong support for a relationship between environmental and social performance, as well as environmental and economic performance. However, the relationship between economic and social performance was deemed insignificant.

The work of Schwarz et al. (2017) focused on evaluating whether kaizen activities could improve the well-being of employees from the Danish Postal Service and a hospital in Sweden. Through SEM, the research suggested that the use of kaizen boards as a visual communication tool did improve employee well-being.

Ghobakhloo and Azar (2018) were interested in the relationships between advanced manufacturing technology (AMT), lean manufacturing (LM), and agile manufacturing (AM) in the Iranian automotive industry. The research focused on using

SEM to analyze the relationships between AMT, LM, and AM and how those affected operational, marketing, and financial performance. The research used Anderson and Gerbing's (1988) two step approach to test the hypotheses. The model found several relationships with high confidence level, including:

- AMT had a strong relationship with lean manufacturing
- AMT had a strong relationship with agile manufacturing
- Lean manufacturing had a strong relationship with agile manufacturing
- Lean manufacturing had a strong relationship with operational performance
- Agile manufacturing had a strong relationship with marketing performance
- Agile manufacturing had a strong relationship with financial performance
- Marketing performance had a strong relationship with financial performance
- Operational performance had a strong relationship with financial performance

Habidin et al. (2018) utilized SEM to explore the intersection of lean manufacturing practices (LMP), ISO 14001, and environmental performance (EP) in Malaysian automotive manufacturers. The research found that LMP implementation had a direct, positive, and significant impact on EP and on ISO 14001. However the impact of ISO 14001 on EP was found to be insignificant, unless considering LMP as well. When ISO14001 is considered as a mediator between LMP and EP, there was an increase in the impact on EP.

Burawat (2018) utilized SEM to validate the positive relationship between lean, operational performance, and financial performance in Thai manufacturing companies. The research concluded that successful lean implementation would lead to better financial performance.

2.3. PRINCIPAL FINDINGS OF THE SYSTEMATIC LITERATURE REVIEW

As shown in Figure 2, there was consistent growth in the number of articles published each year beginning in 2006 with a peak of eight papers published in 2016. Since that time the numbers have dropped off a bit but still show significant interest in the topic.

As the review was being conducted it became apparent that a few countries were more highly represented than others. That can be seen in Figure 3. While there was a good representation of different countries, India far surpassed most other countries with eleven publications. The United States and Malaysia followed India with seven and six publications, respectively.

Table 2 lists the factors that were listed as being critical to successful implementation of lean along with the associated research study. It is important to note that not all of the papers reviewed in this study provided CSFs. The CSFs were extracted from the papers and cataloged. Each paper was then reviewed. In cases where similar CSFs were identified with similar intent or naming, they were reduced to a single CSF. The original list of CSFs contained 84 factors which were reduced to 32 factors, as shown in Table 2 and Figure 4.

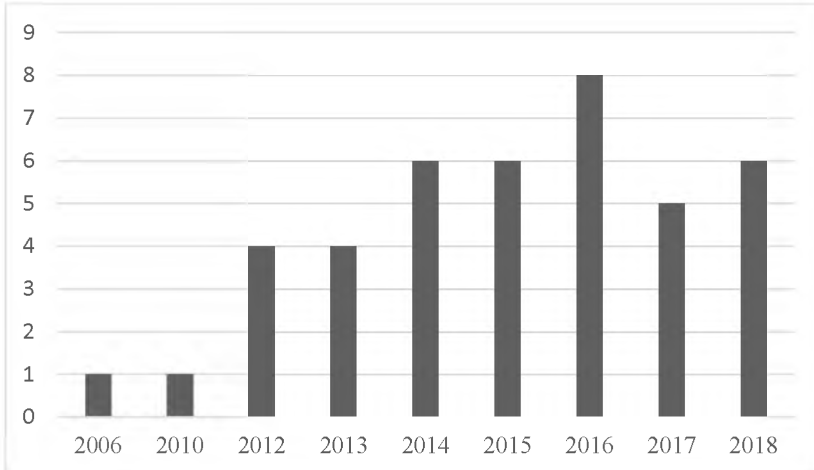

Figure 2. Publications by year

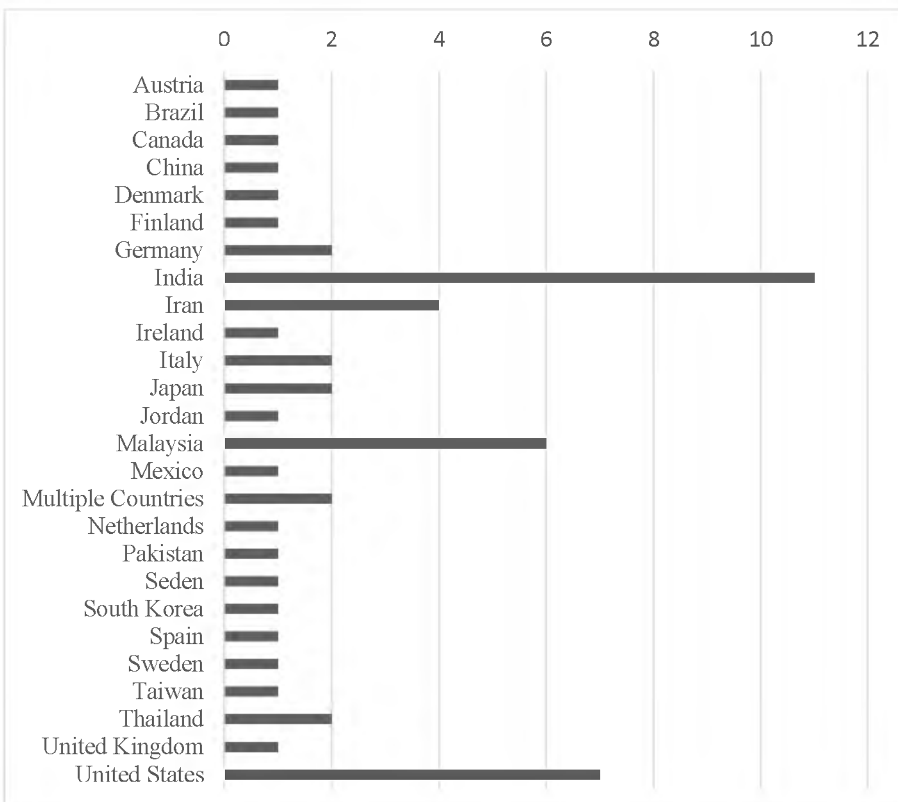

Figure 3. Publications by country

Table 2. Critical success factors

Factor	**Research Study**
Customer partnership	Habidin and Yusof (2013); Sangwan et al. (2014); Chavez et al. (2015); Ravikumar et al. (2016); Paranitharan et al (2017)
Effective communication	van Dun and Wilderom (2016); Ravikumar et al. (2016)
Effective leadership	Ravikumar et al. (2013); Habidin and Yusof (2013); Ravikumar et al. (2016); Al-Hyari et al. (2016); Paranitharan et al. (2017)
Employee involvement and engagement	Ravikumar et al. (2013); Randhawa and Ahuja (2016); Ramadas and Satish (2018)
Employee training and education	Nahm et al. (2012); Ravikumar et al. (2013); Sangwan et al. (2014); Dubey and Singh (2015); Ravikumar et al. (2016); Paranitharan et al. (2017); Ramadas and Satish (2018)
Facilitator sensei	Ravikumar et al. (2013)
Financial capabilities	Ravikumar et al. (2013); Ravikumar et al. (2016)
Geographical differences	Hong et al. (2014)
Gross domestic product per capita	Hong et al. (2014)
Implementation process	Noori (2015)
Implementation team	Noori (2015)
Knowledge sharing	Ravikumar et al. (2013)
Leader's self-transcendence values	van Dun and Wilderom (2016)
Lean tools	Cua et al. (2006); Ravikumar et al. (2013); Sangwan et al. (2014); Al-Hyari et al. (2016); Randhawa and Ahuja (2016); Paranitharan et al. (2017); Basu et al. (2017)
Management and strategy	Noori (2015); Ravikumar et al. (2016); Paranitharan et al. (2017); Basu et al. (2017)
Manufacturing strategy Organization size	Paranitharan et al. (2017) Hong et al. (2014); Shah et al. (2015)
Organizational culture	Ravikumar et al. (2013); Noori (2015); Shah et al. (2015); Paranitharan et al. (2017); Ravikumar et al. (2016); Ramadas and Satish (2018)
Organizational culture towards quality	Shah et al. (2015); Basu et al. (2017)
People factors (e.g. Maslow's Theory)	Nahm et al. (2012); Yang and Yang (2013)

Table 2. Critical success factors (Cont.)

Perceived personal benefits of lean	Nahm et al. (2012)
Production system measurement and analysis	Dubey and Singh (2015); Shah et al. (2015); Ravikumar et al. (2016); Paranitharan et al. (2017)
Skills and expertise	Ravikumar et al. (2016)
Soft total quality management	Khalili et al. (2018)
Strategic orientation	Ravikumar et al. (2013); Noori (2015)
Supplier partnership	Sangwan et al. (2014); Chavez et al. (2015); Paranitharan et al. (2017)
Technology management and information system	Paranitharan et al. (2017)
Thinking development	Ravikumar et al. (2016)
Time effectiveness	Bevilacqua et al. (2016)
Top management commitment	Ravikumar et al. (2013); Dubey and Singh (2015); Randhawa and Ahuja (2016); Sreedharan et al. (2018)
Trust in management	Nahm et al. (2012); Ravikumar et al. (2016)
Willingness to learn	Ravikumar et al. (2013)

Figure 4 depicts the number of times each factor was listed as a CSF in the reviewed studies. Employee training and education, lean tools, and organizational culture were the most commonly identified CSFs. Employee training was identified in seven papers with six of the papers focusing on India (as shown in Table 3). Seven papers representing many different countries identified lean tools as a CSF. Lean tools was a collection of activities such as 5S, JIT, TPM, CI, process control, etc. As shown in Figure 4 there were several CSFs identified in multiple papers and many CSFs identified in only one or two papers.

Table 3 shows the country of focus and the resulting factors identified by the author(s). Additionally, the number of studies that related the factor to the specified country is denoted in parentheses. Multiple Countries – 1 contains the following regions;

Europe, Asia/Pacific, North America, South America, Middle East. Multiple Countries – 2 contains the following countries: Germany, Japan, Italy, United Kingdom, United States.

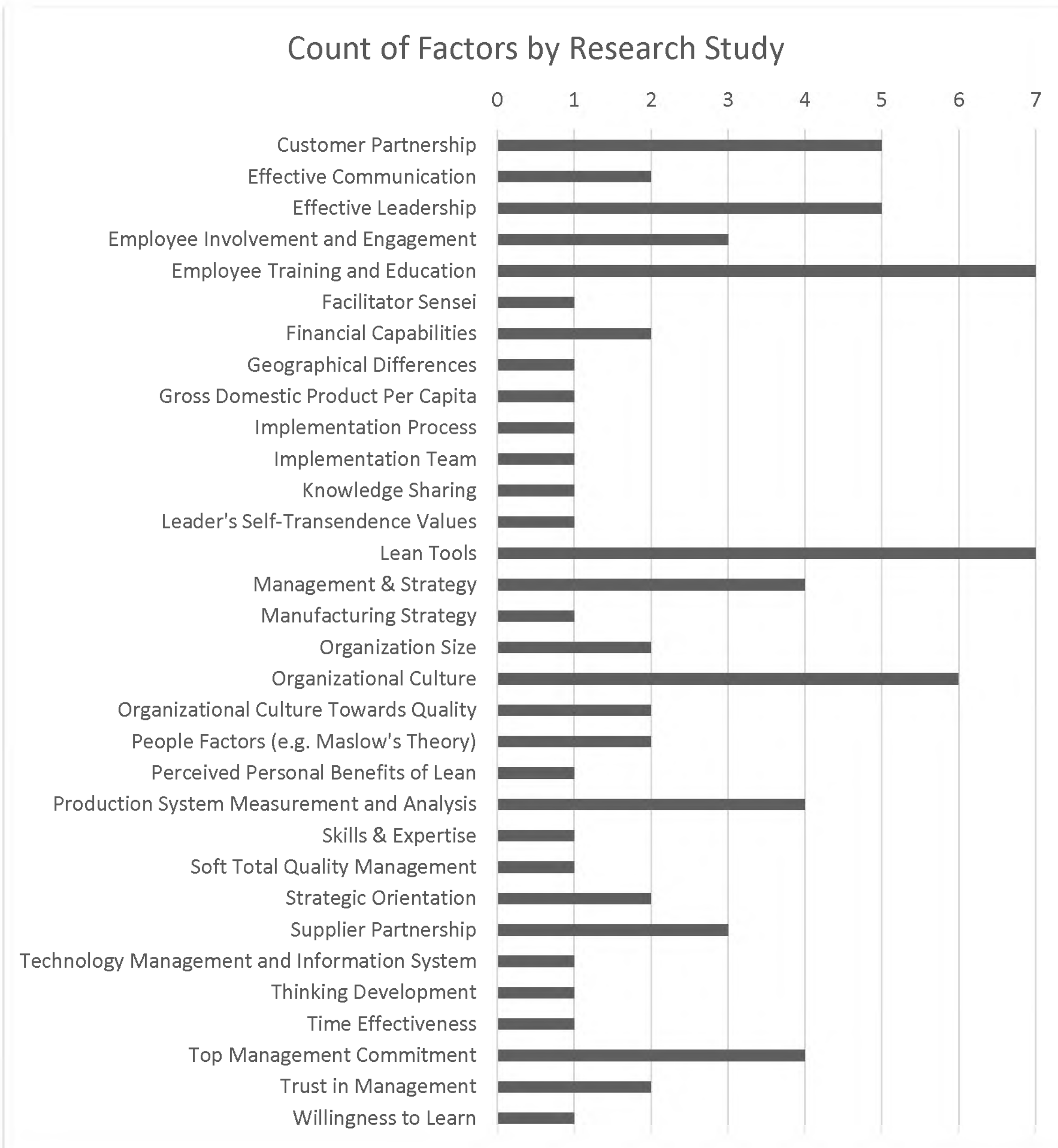

Figure 4. Number of studies identifying each factor

Table 3. Critical success factors by country of study

Factor	**Country**
Customer partnership	India (3); Ireland (1), Malaysia (1)
Effective communication	India (1); Netherlands (1)
Effective leadership	India (3); Malaysia (1)
Employee involvement and engagement	India (3)
Employee training and education	India (6); United States (1)
Facilitator sensei	India (1)
Financial capabilities	India (2)
Geographical differences	Multiple Countries -1
Gross domestic product per capita	Multiple Countries -1
Implementation process	Iran (1)
Implementation team	Iran (1)
Knowledge sharing	India (1)
Leader's self-transcendence values	Netherlands (1)
Lean tools	India (5); Jordan (1); Multiple Countries - 2
Management and strategy	India (4)
Manufacturing strategy	India (1)
Organization size	Multiple Countries -1; Pakistan (1)
Organizational culture	India (4); Iran (1); Pakistan (1)
Organizational culture towards quality	Pakistan (1); India (1)
People factors (e.g. Maslow's Theory)	Tawain (1); United States (1)
Perceived personal benefits of lean	United States (1)
Production system measurement and analysis	India (3); Pakistan
Skills and expertise	India (1)
Soft total quality management	Malaysia (1)
Strategic orientation	India (1); Iran (1)
Supplier partnership	India (2); Ireland (1)

Table 3. Critical success factors by country of study (Cont.)

Technology management and information system	India (1)
Thinking development	India (1)
Time effectiveness	Italy (1)
Top management commitment	India (4)
Trust in management	India (1); United States (1)
Willingness to learn	India (1)

A transcontinental comparative analysis was conducted to further identify research trends as shown in Table 4. The majority of studies were published in Asia ….. No research studies were conducted in Australia, or Antarctica. Africa was not specifically mentioned in a study but the Middle East region was and while the Middle East mainly resides in Asia, it can also include part of Africa. Asia* denotes the study of the Middle East.

It is interesting to note that Asia is listed in all CSFs except for three;

1. Leader's self-transcendence values
2. Perceived personal benefits of lean
3. Time effectiveness

It should be noted that effective leadership was recognized by four studies as being a CSF in Asian countries. However, effective leadership is often characterized in different ways that are very dependent upon the culture and customs of the country. It is possible that leader's self-transcendence values is a CSF for Asian countries as well and simply captured in effective leadership.

Perceived personal benefits of lean was identified as a CSF in North America. Western, and in particular North American countries, are generally considered to be more focused on self and individual benefits than Asian countries so this is not something one would generally expect to see identified as a CSF for Asian countries.

The third CSF not identified for Asian countries was time effectiveness. As with effective leadership, the consideration of time effectiveness is likely very relative to the culture and customs of the country. The meaning and context of "time effective" is likely very different in the United States compared to India or other Asian countries. Culture in the United States tends to be more prompt with regards to time while Asian countries are less so. These cultural differences should be considered when evaluating CSFs by country or continent.

Table 4. Transcontinental analysis of critical success factors

Factor	**Continent**
Customer partnership	Asia (4); Europe (1)
Effective communication	Asia (1); Europe (1)
Effective leadership	Asia (4)
Employee involvement and engagement	Asia (3)
Employee training and education	Asia (6); North America (1)
Facilitator sensei	Asia (1)
Financial capabilities	Asia (2)
Geographical differences	Europe (1); Asia (1), North America (1), South America (1), Asia* (1)
Gross domestic product per capita	Europe (1); Asia (1), North America (1), South America (1), Asia* (1)
Implementation process	Asia (1)
Implementation team	Asia (1)

Table 4. Transcontinental analysis of critical success factors (Cont.)

Knowledge sharing	Asia (1)
Leader's self-transcendence values	Europe (1)
Lean tools	Asia (7); Europe (1); North America (1)
Management and strategy	Asia (4)
Manufacturing strategy	Asia (1)
Organization size	Europe (1); Asia (2), North America (1), South America (1), Asia* (1)
Organizational culture	Asia (6)
Organizational culture towards quality	Asia (2)
People factors (e.g. Maslow's Theory)	Asia (1); North America (1)
Perceived personal benefits of lean	North America (1)
Production system measurement and analysis	Asia (4)
Skills and expertise	Asia (1)
Soft total quality management	Asia (1)
Strategic orientation	Asia (2)
Supplier partnership	Asia (2); Europe (1)
Technology management and information system	Asia (1)
Thinking development	Asia (1)
Time effectiveness	Europe (1)
Top management commitment	Asia (4)
Trust in management	Asia (1); North America (1)
Willingness to learn	Asia (1)

Figure 5 shows the number of publications found by journal. The International Journal of Production Research published three papers, while nine journals covering management, quality, business, and manufacturing published two. Additionally, over twenty journals published only one paper on the topic.

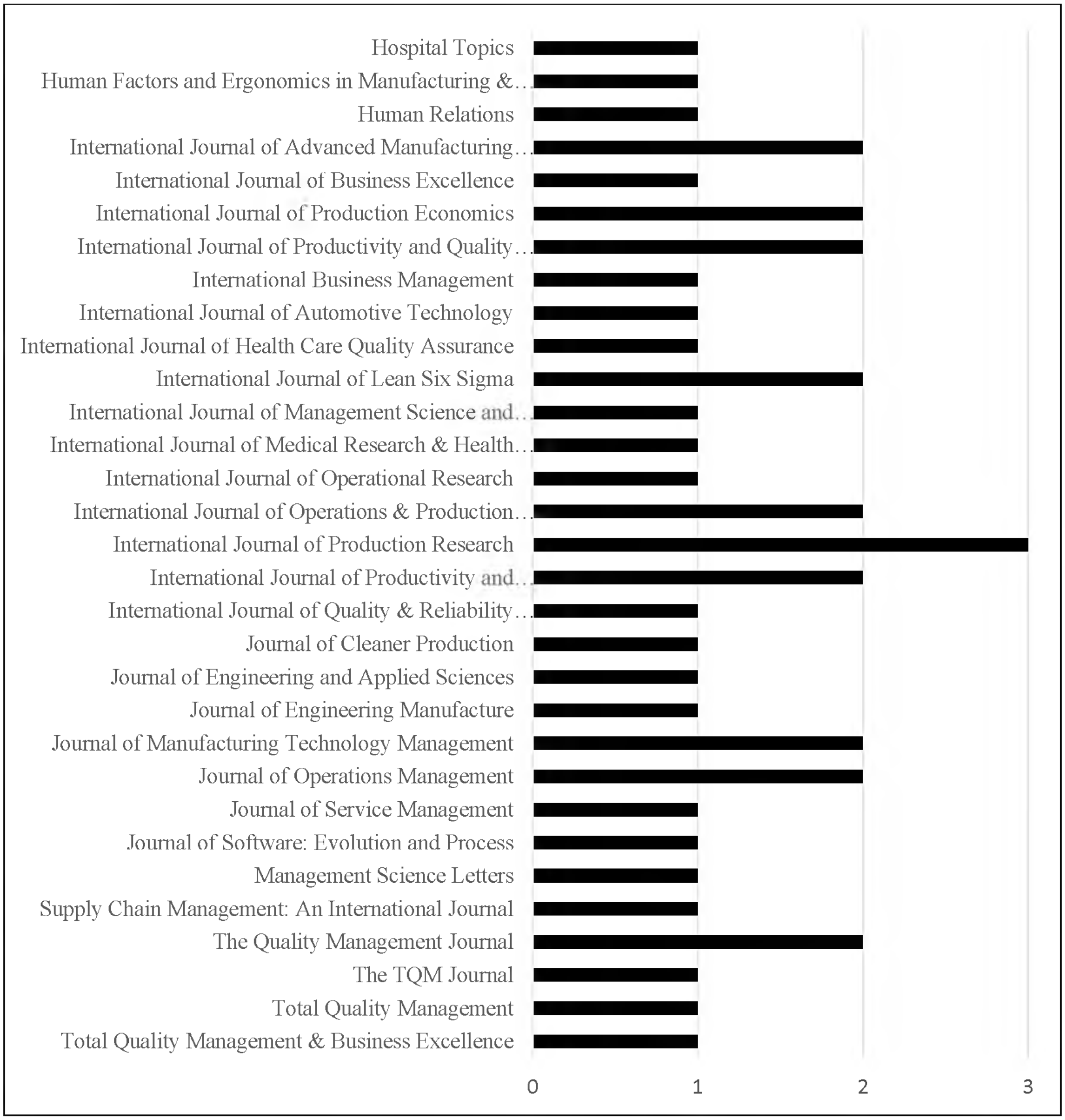

Figure 5. Publications by journal

3. CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

This research was performed to better understand the research that has been conducted that utilizes SEM in identifying CSFs for lean implementation. A systematic literature review identified thirty two unique factors presented in forty one journal articles.

The systematic literature review indicated several key trends. First, the number of publications has continued to increase since 2006. In addition, research is not limited to any specific country; however, India is publishing the most research and is followed closely by the United States and Malaysia. Based on the published research, 32 critical success factors were identified. The three factors most cited were employee training and education, implementation of lean tools, and organizational culture. Further, the research in this area is published in a broad range of journals that focus on production, management, quality, business, and manufacturing.

This study contains several notable limitations. First, only papers published in English were considered. Additional papers in other languages may exist that were not considered. In addition, only papers published in peer reviewed journals were considered. Grey literature such as conference papers and articles on websites were not included. Finally, only papers available through the databases ABI Inform, Web of Science, and SCOPUS were considered as these databases were most relevant to the topic area.

Based on the finding of the systematic literature review, there are several opportunities for future research. One gap identified in the literature was the lack of a global view on developing an implementation model. Most of the studies generating

CSFs were focused on a single country or a small group of countries. Future work may seek to take a global approach in developing a model and determine if a single set implementation drivers can be derived which truly represent critical success factors for implementing lean worldwide.

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II. DETERMINING CRITICAL SUCCESS FACTORS FOR A LEAN CULTURE

ABSTRACT

When making the transition to a lean enterprise, many companies seek to understand if they are ready to begin the culture change required, or perhaps how far along they are in the journey. Some of the questions they may ask are how are we doing?, how far along are we?, and can we make the transition? These types of questions and the desire to develop a tool to answer them, is what drove this research. This paper describes the data collection, analysis, and results of an internationally deployed survey aimed at understanding what factors are critical for a successful lean implementation. The survey respondents represented regions all over the world, with a combined experience of approximately 2,000 years. The survey results were analyzed utilizing regression techniques. Through the analysis several critical factors were identified that directly correlated to a deeply rooted lean culture. The results found that 13 attributes, which correspond to specific survey questions, were identified that accounted for over 90% of the variation in the survey data. Additionally, four factors were identified that accounted for over 82% of the variation. The four survey questions/statements that were the most critical were (1) failures are seen as an opportunity for improvement, (2) what proportion of your organization have received lean training?, (3) a Kanban system is used for flow, and (4) we are always making small improvements in our process. In addition to the details of the survey, review of relevant literature is also discussed. Further, a thorough

review of the regression analysis and results is presented, along with a discussion on the conclusions, limitations, and future work.

1. INTRODUCTION

Over the last thirty years the lean philosophy has been employed to transform the way organizations structure and operate their manufacturing systems. Lean is a philosophy to decrease manufacturing and service times and defects, and also as a whole-enterprise philosophy to eliminate waste and streamline processes and procedures to drive increased efficiency throughout the lean enterprise. While the conceptualization of a lean enterprise is well documented, the realization of such an enterprise often is not as straightforward as implementation strategies might insinuate and the path to successful implementation is ambiguous. With planning, preparation, and determination many companies have followed what began as the Toyota Production System (TPS) and perpetuated the same philosophies throughout their own organizations with varying degrees of success. The principles of lean have been well documented (Womack and Jones, 1990; Kajdan, 2008) and a common set of tools are used to drive the lean enterprise efforts to improve efficiencies, reduce flow times, achieve higher quality, and create superior value throughout the product life cycle, enterprise, and entire value chain. This holistic approach to business is being seen as necessary for any company wishing to remain relevant, competitive, and on the leading edge in their industry.

When trying to understand why some companies are successful in transforming into a lean enterprise, while others are not, one most look at the obvious differences between organizations. One of the most immediate differences that can often be seen between organizations is culture. Not only differences in culture that arise from geographical, religious, political, or ethnic differences, but also differences in company cultures within the same before mentioned cultural spheres.

As organizations begin the journey of transforming into a lean enterprise they often begin without a fundamental understanding of the willingness of their employees to accept and help drive change. The ability to measure and assess the cultural climate of the change agents within a company and their willingness and readiness to help champion the organization's pivot towards lean would be extremely valuable. If an organization's leadership had a tool that could allow them to accumulate information from within their company and utilize that information to produce meaningful, actionable data that could help shape decisions, strategy, and direction as an organization begins down the path of lean, it is likely that the destination could be reached much sooner. After all, it is much easier to get where you are going, if you know where you are starting.

Several studies (Paranitharan et al., 2017; Dubey and Singh, 2015) have utilized statistical techniques to develop models for understanding the relationships between factors identified as critical for successful implementation of lean. The purpose of this research is to further this effort by identifying what critical success factors (CSFs) can help create a positive lean culture within an organization. This is accomplished by analyzing the results obtained from a survey distributed through industrial contacts and social media platforms. The survey is intended to identify factors that are important, if not critical, for a company to consider as it begins a lean implementation.

Several research studies have focused on identifying different cultural aspects that are critical success factors for lean implementation. For example, Ravikumar et al. (2013) identified change in organizational belief and culture as critical for successful implementation of lean in Indian manufacturing companies. While Noori (2015a; 2015b) noted that for hospitals studied in Tehran, Iran, organizational culture has a positive correlation with lean success. The importance of understanding cultural implications related to lean is understood by experts across industries and continents. Shah et al. (2015) identified organization culture as a CSF in the field of software quality. Ravikumar et al. (2016) studied organizations in India of various size and also found that different aspects of organizational culture where critical to the successful implementation of lean. Further, Basu et al (2017b) and Paranitharan et al. (2017) also found organizational culture to be a primary driver of successful implementation of lean in Indian manufacturing companies. Tomic et al. (2017) identified cultural aspects as critical to successful implantation of lean in a Canadian aerospace company and Ramadas and Satish (2018) found that in small and medium enterprises within India, a supportive organizational culture should be considered critical for successful implementation of lean.

The motivation for this study is to understand the impact of various factors on lean implementation to enable organizations to focus their efforts and resources appropriately to increase the chances of a successful implementation. The research has two main objectives:

(1) Develop a comprehensive framework for the relationship between various organizational and cultural factors and lean implementation; and

(2) Identify the most relevant factors that impact lean implementation.

In order to begin to understand some of the cultural influencers and drivers that affect the successful (or unsuccessful) implementation of lean a survey was developed and distributed through internationally through social media in order to identifying the factors that impact lean implementation.

2. RESEARCH METHODOLOGY

For this research, a survey was develop and distributed internationally to develop the proposed model. Prior to distribution of the survey, it was reviewed by international subject matter experts for content validation.

The survey was developed around the key philosophies of lean. One of the pivotal pieces of literature in the area of lean is the book Lean Thinking (Womack and Jones, 1990), which identified five principles of lean. The five lean principles include 1) define value, 2) map the value stream, 3) create flow, 4) establish pull, and 5) pursue perfection. The questions were developed in relation to these five principles.

A 5-point Likert scale was used for many of the questions; however, in some instances, a 5-point scale was not sufficient and an index was created which assigned a unique numerical value to each possible response. Once the survey was developed, it was distributed to several international subject matter experts for review and comment as part of content validation. The panel of subject matter experts represented both academia and industry to ensure the credibility of the survey methodology. Based on their feedback, the survey instrument was revised prior to distribution. Further, institutional review board approval was obtained prior to launching the survey.

The survey was conducted completely online and users were allowed to remain anonymous. The purpose of the survey was to gather sufficient information from a wide range of organizations and regions. Therefore, social media was used to distribute the survey broadly. Further, professional organizations and social media groups were selected that focused on areas involving continuous improvement. The survey was distributed from November, 2016 through August, 2019 to ensure a sufficient response rate. The survey results consisted of 147 responses. Of those 42 were removed during the analysis due to incomplete responses.

Demographic information was collected such as age range, gender, geographic region, and industry of employment. Additionally, multiple questions were asked surrounding the type of lean activities and infrastructure in place at the respondents work location and the perceived effectiveness of lean tools and the degree to which lean was rooted within the organization's culture.

A total of 51 questions were used to gather information on potential explanatory variables for the model and one question was used as the response variable. The question that was selected for the response variable was "The Lean methodology is deeply rooted in the culture of my organization." This question was selected due to the interest in being able to establish a relationship between select factors and the degree of lean implementation within an organization.

The hypothesis tested in this analysis was that lean methodology is deeply rooted in the organizational culture of the respondent based on the 5-point Likert scale previously described. The intent of the model is to allow for prediction of the level to which lean is rooted in an organization through the administration of this survey.

In situations where a large number of potential explanatory variables (30-40 or more) are present, use of a "best" subsets algorithm may not be feasible. In these instances use of an automated search procedure that develops a model based on the "best" subset of explanatory variables may be helpful. One of the most widely used of these automated search procedures is the forward stepwise procedure (Kutner et al., 2004). The forward stepwise procedure (FSP) creates a "best" model by developing a sequence of regression models, adding or deleting an explanatory variable at each step based upon criteria defined in the model parameters (Kutner et al., 2004). For the purpose of this model the entry and exit criteria for each variable was set at a significance level of 0.05.

The aim of the analysis was to develop a model capable of explaining at least 90% of the variation in the data. The initial FSP was only capable of explaining 68.05% of the variation, and contained several outliers and points of high leverage, per the studentized residuals and Cook's D, respectively. These can be seen in Figure 1.

Subsequently, following the FSP methodology, the outliers and high leverage points were removed and the model was reevaluated. This was performed several times until the severity of the outliers and leverage was reduced and the R2 value reached at least 0.90. Four iterations were conducted and 22 points were removed that were either outliers, points of high leverage, or both in order to achieve an R2 value of greater than 0.90. Table 1 shows the R2 results for each step of the FSP at each iteration.

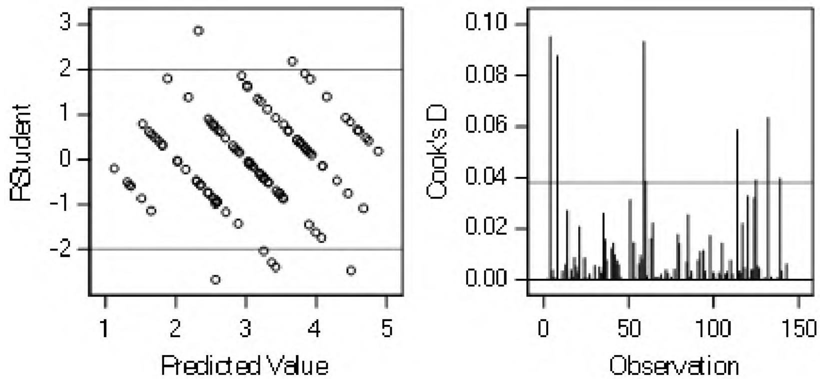

Figure 1. (Left) Studentized Residuals (Right) Cook's D for the initial FSP

Table 1. R^2 value at each step of the iteration

		Iteration			
		1	2	3	4
	# Obs Read	147	138	130	125
	# Obs Used	105	96	88	83
STEP	1	0.3392	0.4273	0.4524	0.45
	2	0.4871	0.5825	0.6237	0.7034
	3	0.5448	0.6861	0.7305	0.787
	4	0.5874	0.7149	0.7868	0.8206
	5	0.6199	0.7439	0.8093	0.843
	6	0.6472	0.7596	0.8312	0.8644
	7	0.6652	0.7796	0.8463	0.8751
	8	0.6805	0.7932	0.8567	0.8817
	9	NA	NA	0.8646	0.8895
	10	NA	NA	0.8731	0.8959
	11	NA	NA	NA	0.9016
	12	NA	NA	NA	0.8971
	13	NA	NA	NA	0.892
	14	NA	NA	NA	0.9009
	15	NA	NA	NA	0.9067

The results of the fourth iteration of the FSP are shown in Table 2. The analysis of variance shown provides an overall view of the model's reliability. The sum of squares column indicates that a large portion of the variation is captured by the model. When looking at the model explained variation (83.24337) as a percentage of the total variation (91.80723), we can see that the model accounts for 90.67% of the total variation meaning that 9.33% of the variation is considered error. This percentage (90.67%) is referred to as the coefficient of multiple determination (R2) and can be seen in Table 3. When considering the large F value of 62.74 and low P value of <0.0001, one can conclude that the model provides an adequate representation of the data.

Table 2. ANOVA for forward stepwise procedure

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	11	83.24337	7.56758	62.74	<.0001
Error	71	8.56386	0.12062		
Corrected Total	82	91.80723			

Table 3 details the parameter estimates for the stepwise procedure that was performed. The variables selected by the procedure are listed in alphabetical order by variable letter. The parameters for each variable are listed and along with the standard error, type 2 sum of squares, F statistic, and significance level.

Table 4 shows the summary of the stepwise selection. The variables are listed in order of descending F value. The table also shows the partial R2 for each variable as well as the model R2, which is a running total of error explained by the model by all the variables included in the model at that point. Mallows' criterion (Cp) is used to detect bias in the regression model. The extremely low number when the final variable selection

Table 3. Parameter estimates for forward stepwise procedure

Variable	Survey Question	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	The Lean methodology is deeply rooted in the culture of my organization	-1.22227	0.32661	1.6892	14.00	0.0004
f	In which region do you live/work?	0.09849	0.03090	1.2257	10.16	0.0021
j	How much work experience do you have?	0.12798	0.04425	1.0090	8.37	0.0051
m	What are the annual revenues of your company/organization (in US dollars)?	-0.04670	0.01784	0.8270	6.86	0.0108
n	How much experience do you have in lean?	0.07156	0.02731	0.8278	6.86	0.0108
s	What proportion of your organization has received lean training?	0.10488	0.01393	6.8331	56.65	<0.0001
u	We are always making small improvements in our process.	0.27356	0.04840	3.8537	31.95	<0.0001
x	My group is involved in the development of process metrics.	0.20213	0.05473	1.6451	13.64	0.0004
ab	Failures are seen as an opportunity for improvement.	0.34467	0.05048	5.6230	46.62	<0.0001
ac	My group is involved in defining value added steps for the product.	-0.10597	0.05047	0.5318	4.41	0.0393
af	A Kanban system is used for flow.	0.23358	0.03797	4.5645	37.84	<0.0001
ba	How often do you gather the voice of the customer?	-0.10796	0.02569	2.1311	17.67	<0.0001

is made indicates no bias in the model. Table 4 also shows the F value and significance for each variable. The table indicates a good fit as the variables have large F values and low P values.

During the forward stepwise procedure at steps 12 and 13 variables v and k, respectively, were removed. The variable was removed from the model as part of the FSP to make the model more robust. The reasoning for this can be seen in the significance level in the last column. At step 11, when variable x is added, the significance level of v crosses the 0.05 threshold and is removed. At that point variable k also crosses the threshold and is removed leaving only variables that meet the model criteria of 0.05 significance level.

Table 5 provides the survey questions that were rejected by the model. The survey questions are listed in alphabetical order according to the assigned variable letter.

Diagnostic plots are a useful tool to verify that general model characteristics follow the basic assumptions related to model errors. The assumptions that were made are that the errors were independent, identically distributed, and followed a normal distribution with constant variance. In order to verify these assumptions, diagnostic plots were generated and evaluated. Figure 2 contains the diagnostic plots generated to verify the above assumptions. Variable a in the fit diagnostics plot is the dependent variable that the model is trying to predict. In the top left the first plot in Figure 2 is the residuals versus the predicted values, which illustrates the residual values that should be centered on zero without any obvious outliers or patterns in the data. Since the values of variable a were on a 5 point Likert scale, there is a pattern in the plot as expected; however, no other patterns or severe outliers emerge. The second plot shows the externally studentized residuals (RSTUDENT) versus the predicted values of variable a. This plot helps identify outliers and was used to determine the outliers to remove during the FSP iterations discussed previously. In this case the data is clustered with no severe outliers present. Plot 3 shows the externally studentized residuals versus leverage. This plot was used to determine if an observation may potentially be highly influential on the rest of the model. Points located to the right of the leverage line would potentially be high leverage. While there is one point on the line, there are no points that appear to be extremely high leverage. Cook's D was also utilized in the next plot to look for influence. While there is one observation that appears to be much higher than the rest, the overall magnitude of the observation is not high, and when taken in conjunction with the leverage plot it is of minimal concern. The next plot looks at the dependent variable a values versus the predicted values. This plot helps ensure the normality of the data by verifying the data points are generally centered on the normal line. As indicated in the plot, the data is normally distributed. The normal quantile-quantile plot (Q-Q plot) of the residuals shows that the residuals are approximately normally distributed. If they varied substantially off the normal line or showed significant patterns, then the normality would be in question. The histogram of residuals on the bottom row helps ensure that the error distribution is centered on zero, which it is. The last plot is the residual-fit (RF) plot consisting of side-by-side quantile plots of the centered fit and the residuals. In this plot, the fit plot should be "taller" than the residual plot, which generally indicates that the model is explaining most of the variation in the data. All of the plots appeared satisfactory and the residual plots indicated the data was randomly distributed.

Table 4. Summary of forward stepwise procedure

Step	Variable Entered	Variable Removed	Survey Question	Partial R^2	Model R^2	C(p)	F Value	Pr > F
1	ab		Failures are seen as an opportunity for improvement.	0.4500	0.4500	252.049	66.26	<0.0001
2	s		What proportion of your organization has received lean training?	0.2534	0.7034	101.520	68.35	<0.0001
3	af		A Kanban system is used for flow.	0.0836	0.7870	53.2178	30.99	<0.0001
4	u		We are always making small improvements in our process.	0.0336	0.8206	34.9874	14.61	0.0003
5	j		How much work experience do you have?	0.0224	0.8430	23.4863	11.00	0.0014
6	f		In which region do you live/work?	0.0214	0.8644	12.5971	12.01	0.0009
7	k		*	0.0107	0.8751	8.1546	6.43	0.0133
8	n		How much experience do you have in lean?	0.0066	0.8817	6.2070	4.10	0.0464
9	v		*	0.0078	0.8895	3.5236	5.14	0.0264
10	ba		How often do you gather the voice of the customer?	0.0064	0.8959	1.6710	4.43	0.0389

Table 4. Summary of forward stepwise procedure (Cont.)

11	x		My group is involved in the development of process metrics.	0.0058	0.9016	0.2023	4.16	0.0451
12		v	*	0.0046	0.8971	0.9447	3.29	0.0740
13		k	*	0.0050	0.8920	1.9766	3.52	0.0645
14	m		What are the annual revenues of your company/organization (in US dollars)?	0.0089	0.9009	-1.3726	6.46	0.0132
15	ac		My group is involved in defining value added steps for the product.	0.0058	0.9067	-2.8585	4.41	0.0393
* Indicates the variable was removed from model during stepwise procedure so question not included in table								

Table 5. Summary of survey questions rejected by the model

Variable	**Survey Question**
b	Has the original culture of your organization changed after Lean implementation?
d	What is your gender?
e	What is the existing infrastructure for Lean implementation in your organization?
g	In which industry do you work?
h	Which of the following most accurately describes your primary functional work area?
i	What best describes your level of education?

Table 5. Summary of survey questions rejected by the model (Cont.)

k	Which of the following most accurately describes your occupational title in your company or organization?
l	How many total employees in your company (all branches)?
m	What are the annual revenues of your company/organization (in US dollars)?
o	How many kaizen/lean events have you participated in?
p	What is the average duration of lean projects in your organization?
r	When you provide lean training, how many days is the training?
t	My group is given authority to make decisions related to their work.
v	Managers encourage proactiveness from their employees.
w	Procedures are updated when changes are implemented.
y	Management demonstrates dedication and active commitment to initiatives undertaken.
z	We follow up to make sure improvements continue.
aa	My group understands the difference between value added and non-value added activities.
ad	Batch sizes have been aggressively reduced.
ag	Work in process (WIP) between workstations is limited and actively minimized.
ah	Finished products or services are shipped or provided immediately to the customer.
aj	Improvements from the value stream mapping process are implemented as planned.
ak	The technique 5S is used to organize workstations.
am	Pareto analysis is used to prioritize potential causes of problems.
ao	Improvements are standardized and documented through standard operating procedures (SOPs)
ap	SIPOC diagrams are created to understand all aspects of the process.

Table 5. Summary of survey questions rejected by the model (Cont.)

aq	Waste analysis and poka-yoke are performed to identify and reduce/eliminate waste.
ar	A3 problem solving
as	SMED is used to reduce changeover time and respond effectively to customer demand.
at	A scheduling system decides how much is produced at each workstation.
au	Original contracted deadlines are met for every shipment.
av	Process standards are used throughout the organization at each workstation/workplace.
aw	Corrective actions are carefully evaluated in relation to customer value.
ax	A system to communicate customer feedback throughout the organization is present.
az	My group understands how the customer uses the product/service.

Figure 4 illustrates the work experience of the respondents. Based on the research question, it is preferred that a high number of respondents have substantial work experience to help provide validity to the data. As shown in Figure 4, the respondents overwhelmingly had greater than 20 years of experience.

In addition to work experience, respondents with substantial lean experience was also critical to establishing data validity. Figure 5 illustrates that there was a distribution of lean experience among the respondents, with the majority consisting of mid-career and senior respondents.

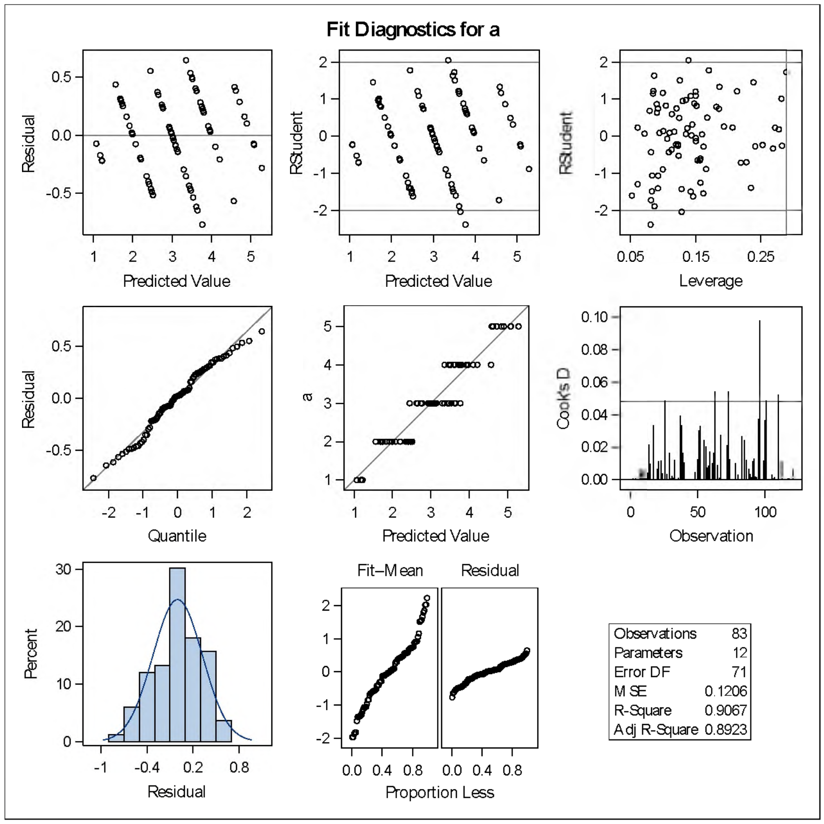

Figure 2. Diagnostic plot of the regression model

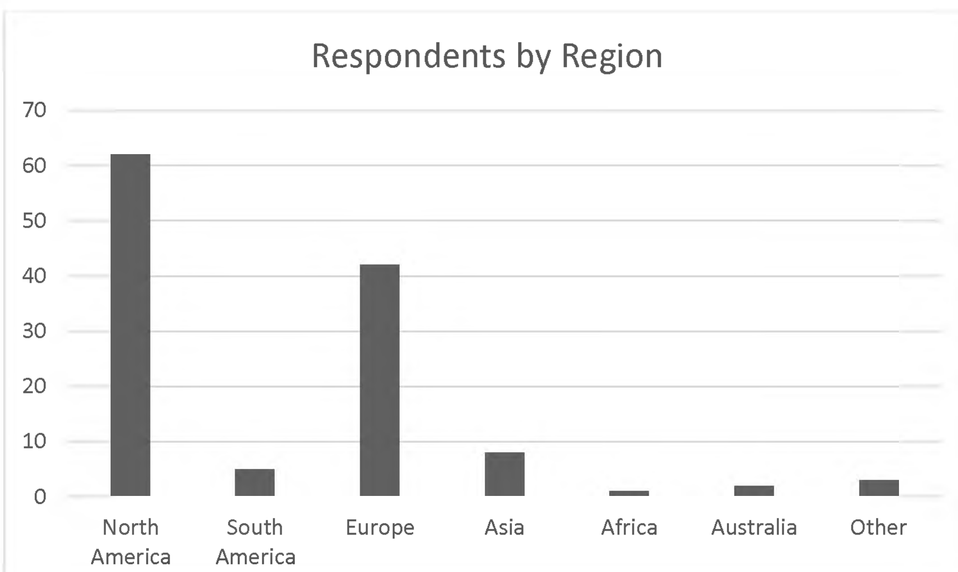

Figure 3. Regional breakdown of respondents

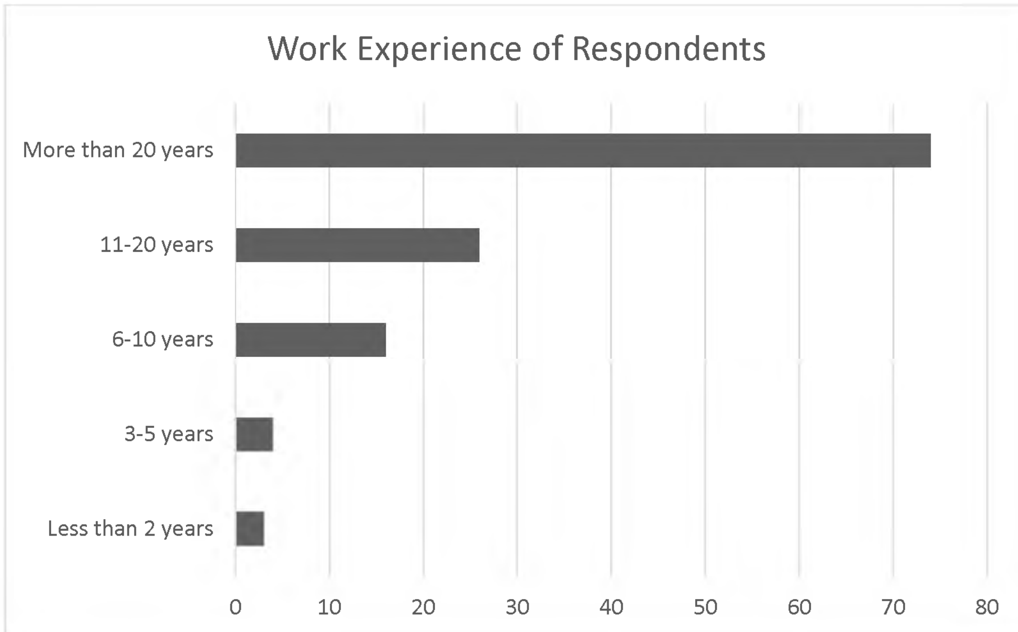

Figure 4. Work experience of respondents

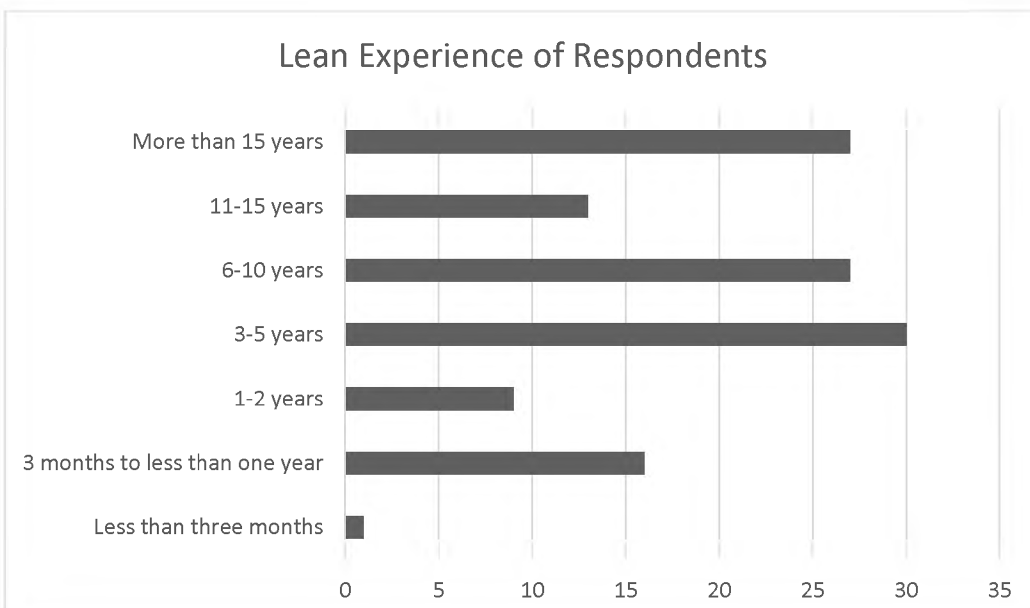

Figure 5. Lean experience of respondents

3. CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH

The forward stepwise procedure was able to fit a model to the data capable of explaining 90.67% of the variation in the data. This is important as the premise of this work is to provide companies key points to focus on when trying to predict if they are ready to implement lean. Further, over 90% confidence in that prediction can be an incredible confidence booster for that organization in their decision. When looking at the results it is important to note that the top four explanatory variables accounted for just over 82% of the variation in the model. This indicates that simply by focusing on these four areas organizations could predict with 82% certainty whether or not they are ready to implement lean in their enterprise. Those four questions/statements are:

1. Failures are seen as an opportunity for improvement.
2. What proportion of your organization has received lean training?
3. A Kanban system is used for flow.
4. We are always making small improvements in our process.

In modern business calculated risk taking and innovative, forward thinking must be central to any successful organization. With this innovative mindset inherently comes opportunity for failure. Because of this, failure cannot be viewed negatively but as a learning opportunity and a natural step on the path of elevating an organization.

Training is another key aspect that cannot be ignored. Basic training, deployed enterprise wide can create common understandings, expectations, and goals. Lean training is essential for providing the fundamental base that a lean enterprise will be built on.

Kanban is a key principle of lean to improve flow; however, it is often a more advanced tool that is used after basic lean tools such as value stream mapping and 5S are implemented. Implementing a Kanban system will help the business run more efficiently and will provide the opportunity for everyone to see the value in lean and can help drive further implementation of lean practices.

Continuous improvement is a hallmark of the lean enterprise. Along with Kanban, creating a culture of continuous improvement will help to strengthen the organization top to bottom. Focusing on and celebrating daily wins at all levels of the organization will foster a culture of lean. In addition, sharing best practices helps promote lean implementation.

Focusing on these four areas should be seen as critical for any organization interested in implementing lean. All four of these speak to the culture of the organization and each one can be directly impacted and improved by effective leadership. By focusing on these four areas companies can position themselves for a successful implementation of lean in their enterprise.

Although the model did have a large sample size of 125 (with 83 being used by the model), this can always be improved upon by collecting a larger sample. Additionally, although the demographics did show representation of each region, the results were heavily favored towards North America and Europe. An increased focus on other regions in the future could provide additional insights.

The model provides a considerable step to identifying general themes, factors, and influencers that contribute to the lean culture in an organization. Four key areas were identified as focus areas for a company interested in beginning a lean journey or those looking to determine how far along they are in the journey. Further analysis and a follow-on study could provide additional information that may be useful for expanding this model and increasing the applicability and usefulness in industry.

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III. USING CLUSTER ANALYSIS TO IDENTIFY FACTORS AFFECTING LEAN IMPLEMENTATION

ABSTRACT

Lean is not a new concept. It has been around for many years now and many companies have benefited from the principles embodied within it. As lean becomes so intertwined within organizations and industries that it begins to produce less of a competitive advantage, it becomes necessary to begin to think about how to expand beyond the current status quo. With the emergence of smart factories and ever increasing connectedness many opportunities exist to regain the competitive advantage once sought in the basic principles of lean. Artificial Intelligence (AI) is a very broad and widely used term. Within AI there are subsets of techniques that can be used to drive decision making. One method in particular is clustering. Clustering algorithms group data without specified labels. They analyze data sets without respect to any labels and seek to group points based on the distance between them. This technique is used in areas such as image processing, financial analysis, genetics, and social networks. One potential application for clustering with respect to lean is to evaluate data from organizations to develop clusters of companies that have successfully implemented lean and those that haven't along with critical success factors that also align with these clusters. This paper seeks to provide a basis by which to begin exploring ways to utilize data to monitor lean implementation within an organization. A survey was distributed via social networking to industry professionals to gather data on what factors could influence lean implementation. This survey data was utilized to perform clustering analysis to gain an understanding of what

factors could be evaluated to determine a company's lean culture. A random forest algorithm, (missForest) was utilized as an imputation method for missing data prior to performing k-modes clustering. The results of the clustering align nicely with the intention of this work. Three clusters were identified with mode values that represent low, medium, and high degree of lean implementation within an organization. Additionally, several other factors were identified which also followed this same convention. These results lend themselves towards the idea that a follow on supervised algorithm could be implemented using this data as a training set to monitor organizations and help them focus on the areas needed to successfully implement lean. Additionally, at the end there will be a brief discussion quickly comparing the results of this study with a forward stepwise regression model built utilizing the same data.

1. INTRODUCTION

The term lean has become engrained into the modern business world. Since manufacturing companies started to adopt the Toyota Production System (TPS) worldwide in the 1980's, lean has transformed from a buzzword for American manufacturing companies into a philosophy that permeates all areas of business worldwide. Lean has become so engrained in many businesses that it is no longer referred to as lean or TPS. Today many businesses have built their own identity for these principles that have become foundational to the way they do business and have rebranded them in ways that reflect the organization's deep seated belief in the fundamental truth that spurred the lean revolution. These principles work. Lockheed Martin's LM21, Boeing's Boeing Production System, and Volvo's Volvo Production System are three examples of this. The principles of waste elimination, continuous improvement, and visual controls, amongst many other principles, are seen throughout organizations and industries and often never referred to as lean. It is no longer just something different that organizations do to create an advantage, more often than not it is a standard that organizations must do to compete at a basic level. Even so, many companies still fail to implement lean successfully, only see limited benefits and never realize the full potential, or fail to identify opportunities outside of traditional manufacturing applications.

The first three industrial revolutions brought about enormous change and advancement throughout the world and the fourth industrial revolution is poised to do the same. What seemed like science fiction not that long ago, is becoming reality today. Industry 4.0, the internet of things (IoT), internet of systems (IoS), smart technology, and artificial intelligence are all connected to and a part of the new industrial revolution. As organizations have begun connecting systems and equipment in new ways, it has produced new data streams and new ways to view organizational health. From a manufacturing perspective, large amounts of machine and process data can be collected fairly inexpensively and used to continuously improve processes and performance, which drives the top-tier performance that originally spurred the widespread adaptation of lean. Industry 4.0 could very well usher in a new era of continuous improvement that relies heavily on dynamic, real-time data to provide feedback and continuously course correct to keep the machines, processes, people, company, and profits headed in the right direction.

In the era of big data and AI, companies are now able to make accurate, real-time predictions to improve their operations. Clustering algorithms are used in areas such as image processing, financial analysis, genetics, social networks, even to make recommendations on what shows you might be interested in watching on streaming services such as Netflix and Hulu Nagy (2018). The algorithms are able to quickly partition the data and find clusters and trend. Xu and Wunsch (2008) describe clustering as an unsupervised classification system whose objective is to partition unlabeled datasets into a finite and discrete set of "hidden" and natural data structures. Essentially, the algorithms explore the data set and seek out patterns or structures in the data that may otherwise be nearly impossible to find. Further, Sathya and Abraham (2013) describe supervised learning algorithms as needing a teacher or supervisor to train examples of classes. Therefore, if one could utilize clustering to identify the data structures around successful and unsuccessful implementation then a supervised learning technique could be implemented to continuously classify data into one of these structures.

Several studies have been conducted to determine different ways to implement clustering in order to increase manufacturing efficiencies or lean implementation.

For example, Qattawi and Madathil (2019) utilized clustering to identify commonality between assembly tasks for different engine models to decrease tooling and station setup and changeover. Antunes and Poshdar (2018) sought to describe a facility rooted in machine learning constantly capturing images from within the facility to monitor and automatically generate material requests, and inventory replenishments, among other operations. Fuzzy-C-Mediods clustering was proposed in (Padayachee & Bright (2017) as a method to cluster manufacturing part families to improve manufacturing cell efficiency. Additionally, Chen et al (2019), Cheng at al (2019), Manns & Deuse (2015), Huang et al (2010), and PengjiaWang et al (2014) proposed different approaches to utilizing clustering methods to increase manufacturing efficiency.

There have also been similar attempts to utilize clustering analysis as part of an approach to assess lean implementation. Marodin et al. (2016) utilized a survey of 64 Brazilian automotive manufacturing firms to gather information on lean implementation. The research utilized a hierarchical algorithm to identify the number of potential clusters and then a k-means clustering approach to allow for discriminating of the original clusters obtained. Netland and Ferdows (2016) utilized a hierarchical and furthest neighbor clustering method as one step in a multiple step process to cluster Volvo plants worldwide based on levels of lean implementation.

One of the immediate applications that could be utilized at the confluence of these ideas is in the area of lean implementation. As mentioned previously, many companies often fail to successfully implement lean in a meaningful way. If organizations could understand the factors that drive a successful lean implementation and monitor their organizational systems, they could constantly classify teams, divisions, or entire business units into a defined readiness level. Along with a readiness level, organizations could also determine focus areas to help drive improvement in the areas deemed as potentially lacking for a successful implementation. This paper proposes a methodology to accomplish the first step in that proposal by utilizing cluster analysis to identify factors that are influential in successful lean implementation. If clusters can be identified that align with successful and unsuccessful implementation of lean, a supervised learning technique can be developed that can aid organizations in successfully implementing lean.

The goal of this research it to utilize clustering algorithms to identify those factors which are important for lean implementation. These factors and data could then be used as a training set for a supervised algorithm to aid organizations in their quest to implement lean.

2. RESEARCH METHODOLOGY

The goal of this research is to propose a technique that can be used to analyze survey data and identify the factors that are influential towards the successful implementation of lean in organizations. The research methodology included survey distribution and collection, pre-cleaning of the data, and implementation of the k-modes clustering algorithm in R. Further, the results of the clustering algorithm will be discussed along with analysis of the implications. Additionally, regression analysis was performed on the same data set and compared to the results of the cluster analysis.

The data used in this work was obtained through a survey distributed on LinkedIn to industry professionals. Prior to distribution of the survey, Institutional Review Board (IRB) approval was obtained through Missouri S&T. A total of 196 responses were obtained covering 52 questions. Initial data cleaning was performed to eliminate any responses that were missing responses to more than 50% of the questions. This removed 51 responses from the data set. All 51 of these responses had started to fill out the survey and answered a small portion of the initial demographic questions and then exited the survey. There were no responses to any of the questions concerning lean and, therefore, were removed from the data set.

Many of the questions were based on a five-point Likert scale; however, some were not. Some questions provided the respondent with more options to choose from. For example, the respondents were asked to identify the region in which they live and they were provided with six options to choose from. Respondents were also asked to identify the industry in which they work and were provided with 42 options to choose from. All of the responses were transformed into numeric factors to simplify the analysis. In the previous two example questions mentioned, the six regions were transformed into numeric factors one through six. Similarly, the industry responses were transformed into numeric factors one through 42. All responses for all questions were categorical in nature.

Figure 1 summarizes the number of respondents by region. The goal of this survey was to capture a diverse, global sample. As shown, while there was representation from many different regions, North America was by far the most heavily represented with Europe the second most represented. Beyond North America and Europe the representation of other regions was sparse.

Figure 2 provides the work experience of the survey respondents. By far the most represented group falls into the “more than 20 years” of experience group. However, there was also strong representation of responses from mid-career and early career as well.

Figure 3 details the lean experience of the survey respondents. As indicated, there is a broad mix of experience from a few months to over fifteen years. This mix of lean experience should help to provide a more thorough view on the survey questions as opposed to having all respondents with very little experience or all respondents with 15+ years of experience.

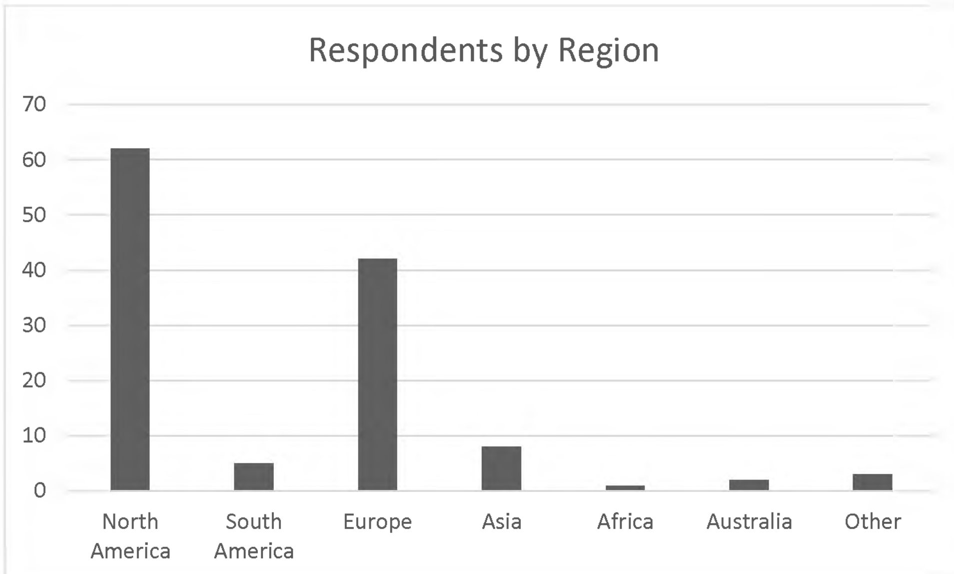

Figure 1. Survey respondents by region

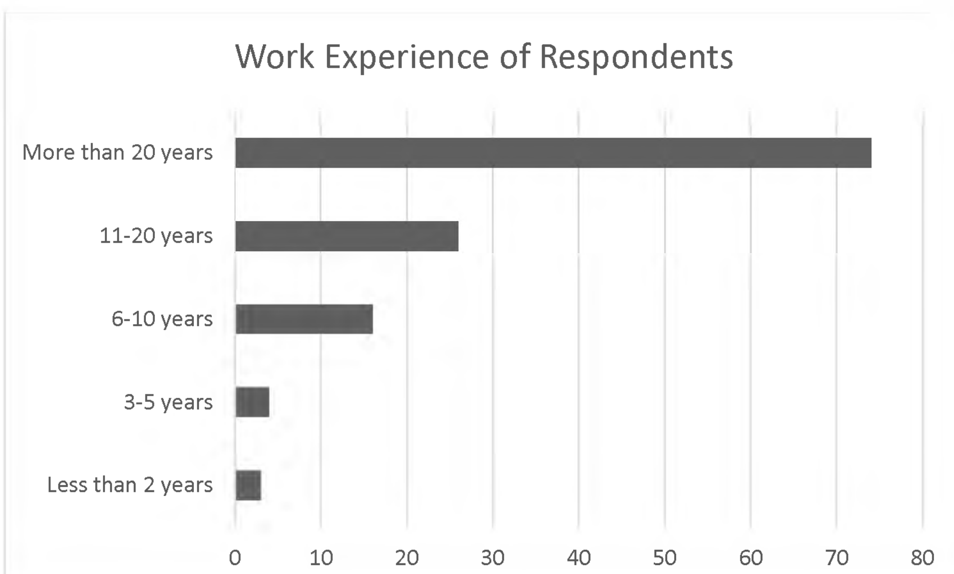

Figure 2. Work experience of survey respondents

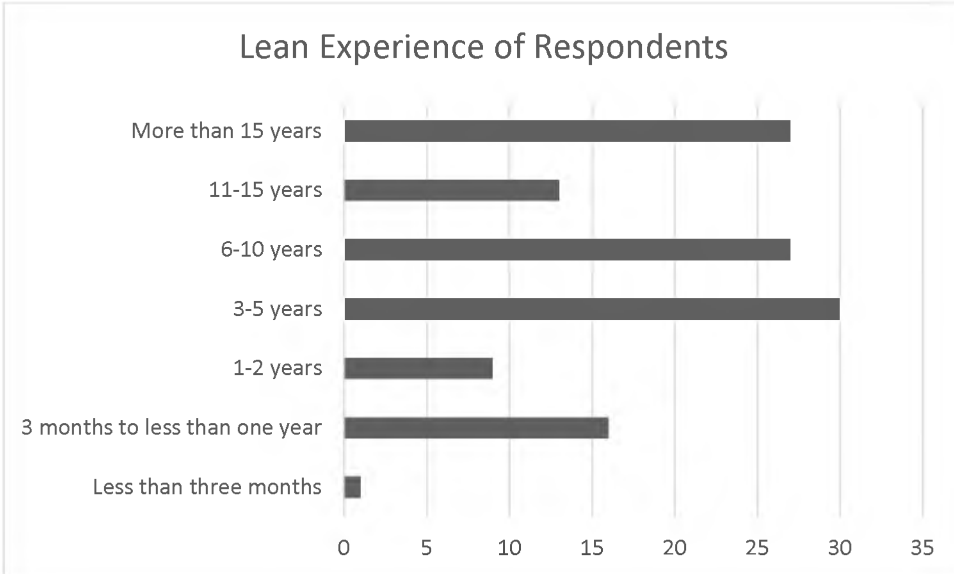

Figure 3. Lean experience of survey respondents

After the initial cleaning and transformation of the data to numeric factors many responses were still missing some data. In total 516 data points (6.8% of the total data set) were missing. In order to address the missing data, an imputation method based on the random forest (RF) algorithm was selected. Stekhoven & Buhlmann (2011) proposed an RF method (missForest) for imputing missing data onto data sets containing mixed data types. The method needs no tuning parameter and, therefore, requires no prior knowledge of the data and is simple to use. Additionally, the method has been shown to outperform many other common methods for imputing categorical data and is a readily available package in R.

One of the parameters that the user is able to set when using missForest is the number of node trees. The default value is set to 100. The initial runs were performed with the number of nodes set to 100 to determine the amount of run time and iterations that would be required. With the number of trees set to 100, each iteration took approximately 22-25 seconds to run and the algorithm required four iterations to find the solution. When the trees was set to 200, the algorithm required three iterations and each one took between 43-47 seconds to run. The out of box error estimate (OOBEE) provided by the algorithm when using 200 node trees was slightly better than when using 100. Further, when utilizing 500 node trees, the computational time was significantly larger, at about 110 seconds per iteration and required three iterations. Also, the OOBEE was not better than the result when using 200 node trees. Considering the difference in computational time when compared to the OOBEE it was decided to utilize 200 node trees.

There are many algorithms documented in the literature capable of handling categorical data. Ahmad and Khan (2019), Ganti et al. (1999), Zhang et al. (2000), San et al. (2004), and Gan et al. (2009) documented various approaches to clustering categorical data. Chaturvedi et al. (2001) proposed the K-modes clustering procedure based on the traditional K-means procedure. The K-modes algorithm was designed to derive clusters from categorical data by explicitly optimizing a loss function. It is nonparametric because it does not make any distributional assumptions about the data and it circumvents the need to define ad hoc distance measures on the categorical data to be clustered. K-modes was shown to perform at least as well as other categorical classification methods while being much less computationally expensive.

When utilizing most partitioning style clustering algorithms (such as k-modes) it is required for the user to select the number of partitions (clusters) for the algorithm to use. This is generally seen as one of the main drawbacks of partition based clustering algorithms as it requires the user to have advanced knowledge of the dataset in order to be able to make a reasonable assumption on an appropriate number of clusters. In this particular case, it is desired to be able to identify three clusters in the data relating to low, medium, and high values of the questions related to lean implementation.

Based on the information presented above, for the purpose of this work the K-modes algorithm was selected and implemented in R. This decision was made largely because of the widespread use of and commonality of the algorithm. It is a very common algorithm to use for clustering categorical data and is readily available in many software languages. This work was performed in R version 3.5.3. The klar and missForest packages were installed in R and used for this work for clustering and imputation, respectively.

3. RESULTS

The algorithm identified three clusters, which corresponded to low, medium, and high values for many of the lean implementation factors. Figure 4 shows the number of data points in each cluster. The x axis represents the sequential observation number of each data point. The y axis denotes the cluster assignment and the number of points in each cluster. As shown, cluster 3 had the highest number of points assigned to it with 1984. Cluster 2 had 1181 and cluster 3 had 535 points.

One interesting note about Figure 4 is that there does appear to be grouping for some of the data points relative to the observation number for clusters 1 and 2. The observation numbers were sequential based on the date and time the survey was taken. It may possibly be due to the fact that as an individual completed the survey, their peers and colleagues were able to see they completed it through LinkedIn, thereby prompting them to complete the survey themselves. If this were true, it could lead to pocket of individuals with similar professional experiences, perhaps even within the same organization, to complete the survey within a short time of each other.

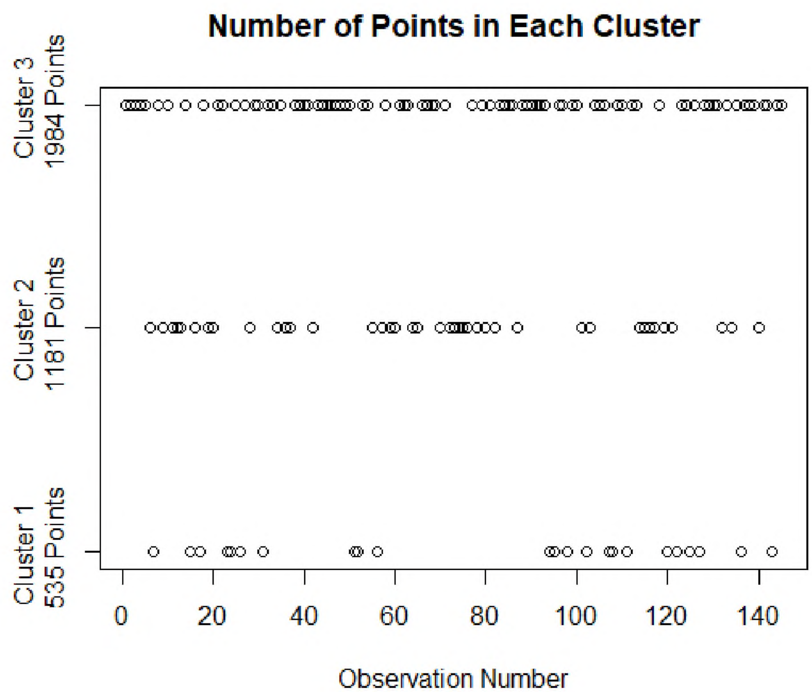

Figure 4. Number of points in each cluster

The analysis results are provided in Table 1 for each of the survey questions that were used in the analysis. In addition, the number of missing data points from the data set that was used, after the initial data cleaning describer earlier are provided as well as the the OOBEE from missForest imputation, mode value for each question and cluster, and partial R2 for each question that was determined using regression.

The OOBEE provided by missForest is the proportion of falsely classified entries (PFC) of the imputed data set Stekhoven & Buhlmann (2011). Good performance of the missForest algorithm leads to an OOBEE close to 0, while bad performance produces an OOBEE close to 1. The number of missing data points are relatively low, and even though some of the OOBEE are quite high, when considering the low number of points being imputed, an error of this size is still preferable to the loss of data that would occur if those observations were eliminated from the analysis Stekhoven & Buhlmann (2011).

The cluster modes indicate the mode value for each question in the specified cluster. For most of the questions of interest, the responses were based on a five-point Likert scale where 1 indicates a low score and 5 a high score. Other questions had a slightly larger scale but still had lower values represented by smaller numbers, and higher values represented by larger numbers. Other questions such as “In what region do you live?” do not follow this same approach and will be discussed separately.

As shown in question “a” the three clusters line correlate to high, low, and medium values. The mode value for cluster 1 is five, for cluster 2 the mode value is two, and for cluster 3 the mode value is three. The remaining questions also highlight that other pertinent questions indicate a similar high, low, and medium classification related to the clusters. Beginning at question “m”, even though clusters 2 and 3 both have a mode value of four, cluster 1 has a mode value of seven, which does indicate higher level of lean experience coinciding with question “a”. Additionally, questions “q” through “ay”, all seem to follow this same pattern of cluster 1 being the higher value, cluster 2 being the lower value, and cluster 3 being the medium value. Although in some of these, the mode value for cluster 2 and cluster 3 is the same, the higher value still corresponds to cluster 1.

Another interesting note involves the mode values for question “f”. The mode value for cluster 1 is eleven and for cluster 2 is twenty three. The mode value of eleven represents the consulting industry while the mode value of twenty three represents the manufacturing industry. As shown in Table 1, the mode value for question “f” in cluster 1 is the consulting industry while the mode value for question “f” in clusters 2 and 3 is the manufacturing industry. This could indicate a number of things. Perhaps consultants have a more positive outlook? Or perhaps consultants generally only see a small snapshot of what an organization is truly like and do not get to experience the day-to-day as those in the organization? Or perhaps consultants are better able to identify the small and large things within an organization that are contributing to the success (or lack thereof) and are better able to see it with a more objective view?

Some other items to point out are that the majority of the respondents were from North America (question “e”). The majority of the respondents were male (question “c”). The majority of the respondents work in production or operations (question “g”). The majority of the respondents have a graduate degree (question “h). The majority of the respondents have more than 20 years of work experience (question “i”). Since these populations constituted the majority of the responses, it did not allow this analysis to distinguish how these factors may affect lean implementation.

The last piece of information presented in Table 1 is the results of the stepwise regression that was performed on the same data set. In this analysis the response variable was question “a”. The explanatory variables that were selected are denoted by having their partial R2 value listed. Those with an asterisk (*) were identified as being one of the top four explanatory variables. As expected, all four of those explanatory variables relate with the clusters presented. Question "a" was the response variable and is denoted as "RV".

Table 1. Imputation and clustering results

Question		Number of Missing Data Points in Data Set	Imputation OOB Error Estimate	Cluster 1 Mode	Cluster 2 Mode	Cluster 3 Mode	Regression Model Partial R^2
a	The Lean methodology is deeply rooted in the culture of my organization.	0	0	5	2	3	RV
b	Has the original culture of your organization changed after Lean implementation?	21	0.2419	1	1	1	NA
c	What is your gender?	4	0.1418	1	1	1	NA
d	What is the existing infrastructure for Lean implementation in your organization?	0	0	5	3	4	NA
e	In which region do you live/work?	0	0	1	1	1	0.0214
f	In which industry do you work?	1	0.6319	11	23	23	NA
g	Which of the following most accurately describes your primary functional work area?	0	0	19	19	19	NA
h	What best describes your level of education?	0	0	7	7	7	NA

Table 1. Imputation and clustering results (Cont.)

i	How much work experience do you have?	0	0	5	5	5	0.0224
j	Which of the following most accurately describes your occupational title in your company or organization?	0	0	1	19	14	NA
k	How many total employees in your company (all branches)?	2	0.7272	6	8	8	NA
l	What are the annual revenues of your company/organization (in US dollars)?	0	0	10	9	10	0.0089
m	How much experience do you have in Lean?	0	0	7	4	4	0.0066
n	How many kaizen/lean events have you participated in?	0	0	5	5	5	NA
o	What is the average duration of lean projects in your organization?	4	0.3333	6	6	6	NA
p	How are projects executed in your organization?	3	0.3521	1	3	3	NA
q	When you provide lean training, how many days is the training?	3	0.8521	7	2	3	NA
r	What proportion of your organization has received lean training?	2	0.7832	11	3	1	*0.2534
s	My group is given authority to make decisions related to their work.	7	0.4637	5	4	4	NA

Table 1. Imputation and clustering results (Cont.)

t	We are always making small improvements in our process.	7	0.4855	5	4	4	*0.0336
u	Managers encourage proactiveness from their employees.	7	0.5217	5	3	4	NA
v	Procedures are updated when changes are implemented.	7	0.5362	5	4	4	NA
w	My group is involved in the development of process metrics.	7	0.5580	5	3	4	0.0058
x	Management demonstrates dedication and active commitment to initiatives undertaken.	7	0.4855	5	4	4	NA
y	We follow up to make sure improvements continue.	7	0.5507	5	4	4	NA
z	My group understands the difference between value added and non-value added activities.	7	0.5217	5	4	4	NA
aa	Failures are seen as an opportunity for improvement.	7	0.5580	5	3	4	*0.45
ab	My group is involved in defining value added steps for the product.	7	0.5507	5	4	4	NA
ac	Batch sizes have been aggressively reduced.	15	0.6308	5	2	3	NA
ad	The "Just-in-Time" concept is a part of daily routine in the workplace.	14	0.5115	5	2	4	NA
ae	A kanban system is used for flow.	15	0.5846	5	3	4	*0.0836

Table 1. Imputation and clustering results (Cont.)

af	Work in process (WIP) between workstations is limited and actively minimized.	14	0.4885	5	3	4	NA
ag	Finished products or services are shipped or provided immediately to the customer.	14	0.5191	5	4	4	NA
ah	Value stream mapping is undertaken to understand how activities create value for the customer.	16	0.5581	5	3	4	NA
ai	Improvements from the value stream mapping process are implemented as planned.	16	0.5039	5	3	4	NA
aj	The technique 5S is used to organize workstations.	16	0.5039	5	4	4	NA
ak	Training programs are an integral part of an employee's development at the workplace.	16	0.4264	5	4	4	NA
al	Pareto analysis is used to prioritize potential causes of problems.	16	0.5039	5	3	4	NA
am	Fishbone diagrams are used to brainstorm potential causes of waste or defects.	16	0.5194	5	4	4	NA
an	Improvements are standardized and documented through standard operating procedures (SOPs)	16	0.5736	5	3	4	NA

Table 1. Imputation and clustering results (Cont.)

ao	SIPOC diagrams are created to understand all aspects of the process.	16	0.5039	5	3	4	NA
ap	Waste analysis and poka-yoke are performed to identify and reduce/eliminate waste.	16	0.6357	5	3	4	NA
aq	A3 problem solving	16	0.5194	5	3	4	NA
ar	SMED is used to reduce changeover time and respond effectively to customer demand.	16	0.4806	5	3	4	NA
as	A scheduling system decides how much is produced at each workstation.	23	0.6230	5	4	4	NA
at	Original contracted deadlines are met for every shipment.	23	0.5410	5	3	4	NA
au	Process standards are used throughout the organization at each workstation/workplace.	20	0.4080	5	3	4	NA
av	Corrective actions are carefully evaluated in relation to customer value.	23	0.4590	5	4	4	NA
aw	A system to communicate customer feedback throughout the organization is present.	17	0.4844	5	4	4	NA

Table 1. Imputation and clustering results (Cont.)

ax	Customer requirements are clearly communicated at each stage in the journey of the product/service; from concept to delivery to the customer.	17	0.4609	5	2	4	NA
ay	My group understands how the customer uses the product/service.	17	0.5234	5	4	4	NA
az	How often do you gather the voice of the customer?	18	0.8740	4	1	6	0.0064

4. CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH

The method proposed using a k-modes clustering approach to identify success factors critical to successful implementation of lean is a viable approach. This research methodology was successful in identifying three clusters corresponding to low, medium, and high degrees of implementation along with implementation factors that corresponded to low, medium, and high implementation. This information could be used in the future to help monitor an organization's lean implementation and provide feedback on areas to focus on to help increase the degree of implementation.

As with any research, there are limitations. When considering an analysis of a very large population of people a large sample size is typically desired. The survey used in the execution of this research utilized 196 responses. From those 196, 51 were removed in the initial cleaning due to over 50% of the questions being unanswered. After this initial cleaning 6.8% of the total data set was still missing. Even though the 6.8% of missing data was imputed, when considered along with the 51 responses removed, the amount of data obtained from the survey should be considered a limitation. This could be due to the survey's length. The survey was extremely comprehensive which could have led to survey fatigue. Another limitation to note is the overwhelming number of respondents from North America and Europe. Since this research was aiming for a global view, the limited number of respondents from other regions needs to be noted. One factor that may have affected this is the fact that the survey was only offered in English which could have limited the ability of people in other regions to respond. Additionally, most of the people responding to the survey reported extensive work experience, with only two people reporting less than two years' experience. While obtaining responses from experienced people is generally a positive outcome, having a very small number of less experienced people responding can prevent the capture of diverging perspectives. These diverging perspectives can often be used to gain insights that otherwise go unnoticed.

As mentioned previously, this work could be used as the training set for a supervised learning algorithm. The supervised algorithm could be employed by organizations to monitor lean implementation preparedness and execution while making recommendations on areas of focus. Additionally, a follow-on survey could be created which is more targeted in its approach with fewer questions and distributed to a wider audience and made available in multiple common languages. This could result in a higher, more diverse response rate and enable the creation of a higher fidelity training set utilizing the clustering method described here.

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SECTION

2. CONCLUSIONS AND RECOMMENDATIONS

2.1. CONCLUSIONS

The original contribution of this research was the establishment of a predictive model that can be utilized by organizations to gauge their readiness to implement lean. Additionally, a cluster analysis was performed which developed a training data set that can be further utilized to monitor an organization's implementation level or readiness level. These approaches provide both a simple to understand and execute model as well as a more advanced artificial intelligence approach that can be used more dynamically utilizing an organizations data streams. Both of these approaches can help an organization assess their progression along their lean journey.

2.2. RECOMMENDATIONS

The data utilized for this research came from a survey distributed widely via LinkedIn. While there were 196 respondents, 51 of those had to be removed due to the majority of the survey being incomplete. While 145 respondents is still a considerable sample size, a larger sample size would certainly be an objective in future work.

While the survey was distributed internationally through social media, no incentive was provided to take the survey. It is recommended in future research to provide a small incentive (or other means of motivation) to increase the response rate.

Another recommendation would be to develop a much more concise survey. The survey that was utilized was very thorough and, therefore, took time to complete, likely leading to survey fatigue and incomplete results. Future work should focus on improving the survey finish rate by shortening the amount of time needed to complete.

Additionally, the survey that was distributed was only available in English, which certainly limited the ability of people in different countries to respond. Future work should also focus on developing the survey in multiple common languages.

Another potential consideration for future work would be to consider product volume and mix within an organization as a factor contributing towards lean implementation success. An organization with a high product mix and low volume may inherently have greater difficulty implementing lean than an organization with low product mix and high volume.

The focus of the work presented here was the development of models to predict lean implementation success, future work should consider validation of these models through analysis of new data sets. In addition, the models presented here could be validated through implementation within an organization.

VITA

Richard Charles “Charlie” Barclay earned his PhD in Engineering Management from Missouri S&T in December of 2020. In addition to his PhD, Charlie earned a B.S. in Mechanical Engineering and a M.S. in Manufacturing Engineering, both degrees coming from Missouri S&T in 2012 and 2013, respectively. In addition to his PhD work, Charlie was a Hardware Design Manager for The Boeing Company in St. Louis supporting Boeing Global Services – Training Systems. In this role Charlie was responsible for leading a team of Electrical, Mechanical, and Systems Engineers in the development and design of advanced training solutions for the US and ally warfighters. These training solutions ranged from maintenance trainers to full-motion flight simulators for the most advanced military aircraft on the planet. Prior to this role, Charlie spent two years as a Production Engineering Manager for Boeing Defense, Space, and Security in St. Louis where he held a variety of roles including leading the 777X Production Engineering fixed leading edge and empennage assembly team and the Composite Center of Excellence Manufacturing Engineering team. Prior to moving to St. Louis Charlie spent five years with Boeing Research and Technology as a Materials, Process, & Physics Engineer supporting composite fabrication for the 787 fuselage in Charleston, SC. Charlie was a 2019 graduate of Leadership Next, Boeing’s two year leadership development program, and he held five US Patents related to laser ablation technologies.