An International Delphi Study to Build a Foundation for an Undergraduate-Level Lean Manufacturing Curriculum

Hiral A. Shah, Ph.D., CEI, PEM, PMP
St. Cloud State University
hashah@stcloudstate.edu

Tracy Tillman, Ph.D., CEI, PEM, CMfgE

Abstract

This paper is based on research that was conducted to identify and validate the competency areas included in the body of knowledge developed by a consortium of the Society of Manufacturing Engineers (SME), the Association for Manufacturing Excellence (AME), and the Shingo Prize for three levels of certification examinations in lean manufacturing, namely Bronze, Silver, and Gold. The focus of the paper is to delineate the results obtained from the Bronze level certification exam that can be applied to lay a foundation for developing an undergraduate-level curriculum in lean manufacturing. A modified Delphi technique that included a pre-Delphi round followed with three rounds of Delphi questionnaire iterations was used in the study. Seventy-six experts, from six different countries, selected to serve on the Delphi panel rated the importance of competency areas for testing at each level of lean certification using a 5-point Likert scale and provided additional comments. A convergence of opinion on the competency areas provided a basis for validating the body of knowledge for Bronze, Silver, and Gold levels of lean certification examinations. Forty-two prioritized competency areas that emerged from the study were organized as a body of knowledge and were grouped into five major domains: (a) Enablers for Lean, (b) Lean Core Operations, (c) Business Core Operations – Support Functions, (d) Quality, Cost and Delivery Measures, and (e) Business Results. This body of knowledge serves as a model for developing an undergraduate-level curriculum in lean manufacturing.

Introduction

The focus of lean manufacturing is to obtain highest quality, lowest cost, and shortest lead time by continuous elimination of waste [1]. There are various literatures available on lean manufacturing, but none of them unify its body of knowledge. The Association for Manufacturing Excellence (AME) conducted a survey on North American manufacturing companies to explore the degree of awareness about lean techniques among the senior leaders [1]. The results of the study indicated that 41% of the respondents did not really know about lean; 34% were familiar with the idea of lean, but did not know how to go about achieving it; 22% indicated that their firm was on the lean path but they were not obtaining desired results; and 3% indicated that they were on the lean enterprise transformation journey and were obtaining great results [2]. These results reflect a lack of knowledge about lean

principles among a majority of senior leaders in manufacturing firms, as well as their inability to apply the right tools to obtain desired outcomes.

With recent advances and intense competition in the field of manufacturing, there is a great need to educate and employ qualified professionals. The need for a certification exam in lean manufacturing was revealed in a survey conducted on more than 1100 manufacturing industry respondents by the Society of Manufacturing Engineers (SME) [3]. Eighty-three percent of the participants in the survey mentioned that it was either critical or very important to develop an industry standard for lean certification. Moreover, a well-constructed job analysis study would be an essential foundation for a valid, reliable, and legally defensible professional certification program [4].

A role delineation study was conducted for the three levels of the SME/AME/Shingo's lean manufacturing certification exam [5]. The purpose of this paper is to apply the results obtained from the study toward layinga foundation for developing an undergraduate-level curriculum in lean manufacturing.

Review of Literature

The Society of Manufacturing Engineers (SME), the Association for Manufacturing Excellence (AME), and The Shingo Prize for Excellence in Manufacturing (Shingo) collaborated to develop a highly desired lean credential of competence. A description of each of the three levels is as follows:

- Level 1: Bronze Certification – measures the knowledge of basic principles, concepts, and tools of lean as applied to factory, office and service, team facilitation, and appropriate measurement of results.

- Level 2: Silver Certification – measures the capability of lean practitioners in applying lean principles and tools to drive improvements and show measurable results plus orchestrate the transformation of a complete value stream.

- Level 3: Gold Certification – focuses on evaluating the practitioner's strategically focused knowledge and solid understanding of all aspects of lean transformation across the entire enterprise.

The level of difficulty increases from level 1 to level 3, and eligibility criteria also differ on each of these levels. The candidates are to pass a written examination consisting of approximately 150 questions within a three-hour time limit at each level.

Delphi Study

Delphi Technique is a procedure used to obtain consensus on a particular topic through a set of carefully designed sequential survey questionnaires interspersed with feedback from the participants [6]. It is structured to capitalize on the merits of group problem-solving and minimize the liabilities of group problem-solving [7]. Delbecq, Van de Ven, and Gustafson

(cited in Jones [8]) identified five recognized areas of research which have effectively utilized Delphi methodology: (a) determining or developing a range of possible program alternatives; (b) exploring or exposing underlying assumptions or information leading to different judgments; (c) seeking out information which may generate a consensus on the part of the respondent group; (d) correlating informed judgments on a topic spanning a wide range of disciplines; and (e) educating the respondent group as to the diverse interrelated aspects of the topic (pp. 10-11). The Delphi methodology makes the collection of opinions from geographically dispersed experts possible [6]. Moreover, accurate and thoughtful consensus obtained from a group of geographically dispersed experts outweighs the time required to complete the Delphi study. Hence, the Delphi study was used to identify and validate the competency areas needed for developing the three levels of the certification exam.

Research Methodology

A modified Delphi technique with qualitative and quantitative components was used to survey the participants. The data collection process consisted of a Web-based pre-Delphi study and three rounds of email- and paper-based questionnaires.

An initial list of competency areas was developed based on the review of literature and competency areas included in the existing lean manufacturing certification examination. Responses to a set of demographic questions in the pre-Delphi survey were used to select Delphi panel experts for subsequent Delphi rounds. In Round One, the panel members were asked to provide both quantitative and qualitative feedback on the competency areas. During the second questionnaire round, an analysis made of the first round's results was provided for reference. Qualitative feedback obtained from the open-ended questions for each response was provided verbatim along with possible additions or modifications recommended from Round One. Similarly, in Round Three, an analysis made from Round Two was provided to the panel of members and final modifications recommended by them were incorporated.

Data Collection

The sample for this study was obtained by contacting members from the Society of Manufacturing Engineering (SME) and the Institute of Industrial Engineers (IIE) via email who were interested in lean . The questionnaire in the pre-Delphi round was quantitative in nature with additional spaces provided to the participants to include any additional competency areas that they believed to be important to include in the lean body of knowledge.

The pre-Delphi study obtained responses from 138 subjects, out of which 102 Delphi panel members were selected for the first Delphi round based upon the following reported information, which is listed in order of importance: (a) commitment to serve on the Delphi panel, (b) self-rating of their expertise in lean (greater than or equal to 3 on the Likert scale), and (c) years of experience in lean. During Round One, the Delphi panel members who were selected to participate in the study but did not respond to the Round One questionnaire were

contacted to verify whether they were interested in being a part of the study. Based on their responses the Delphi panel was reduced from 102 preliminary members to 76 final members.

The participants were asked to judge importance of a particular competency area for the lean manufacturing exam using a 5- point Likert scale. The following criterion of importance was assigned to the responses provided on the questionnaire, along with an example of how to respond: 4= Extremely important, 3 = Very important, 2 = Important, 1 = Of little importance, 0 = Not important. A "yes" or "no" question was asked to identify the necessity for each specific competency area to be included at each lean certification exam level.

Data Analysis

After searching the literature and examining the data analysis methods used in different fields of study, the methodology utilized by Tillman [9] and Shah [10] seemed to be most applicable to this study. The additional competency areas suggested by participants in the pre-Delphi survey were analyzed and added to the Round One questionnaire under each domain based on researcher judgment and analysis. In Round One, each of the competency areas was given modal and percent of concurrence scores from the pre-Delphi survey results. Data analysis was conducted once all Round One feedback was returned. Each of the competency areas rated in Round One of the Delphi study was given modal and percent of concurrence scores, which were then reflected in the Round Two Delphi questionnaire. Additional comments from Round One that addressed more general concerns about the study were provided in the "Round One Results" document. Data analysis of Round Two was conducted in the same manner as in Round One. Similarly, Round Two results were reported in the Round Three questionnaire. Data analysis of Round Three was performed in the same manner as for Rounds One and Two.

To obtain convergence of opinion, the mean of the standard deviation for each round was calculated. A decrease in the mean standard deviation value indicated a greater convergence of opinion among the panelists. On the basis of the standard deviation scores, the following four categories of the prioritized list were formed (see Table 1): (a) higher mean score, lower standard deviation; (b) higher mean score, higher standard deviation; (c) lower mean score, higher standard deviation; (d) lower mean score, lower standard deviation. A decision of high and low mean and standard deviation was based on the range of results obtained in each category of analysis. An approach followed by Shah [10] and Tillman [9] was followed to determine a cut-off point for defining both high and low mean and high and low standard deviation. Higher and lower values of standard deviations were determined based on the median value of standard deviation under each domain.

Competency areas grouped in Category I were considered to be important for candidates to know for the lean certification exam, and there was relative agreement among panel members on their importance. Competency areas in Category II were also considered to be important for the certification but there was less relative agreement among panel members on their importance.

Table 1: Matrix to Portray Categories for Prioritization

	Standard Deviation in Scoring Low ⟷ High	
High ↑ Mean Score ↓ Low	I Higher Agreement of Greater Importance	II Lesser Agreement of Higher Importance
	IV Higher Agreement of Lower Importance	III Lesser Agreement of Lower Importance

Competency areas in Category III were less important for a lean certification exam than competency areas in Categories I and II, but there was less relative agreement among panel members concerning the competency areas' levels of importance. Competency areas in Category IV were also considered less important for lean certification than competency areas in Categories I and II, and there was relative agreement among panel members on their lower levels of importance.

Results

The demographic information collected in the pre-Delphi round indicated that the majority of the experts were in the age range of 35-54 with most having a Master's degree. About 44% of the respondents possessed at least one professional certification or license. The majority of them were either at a senior management or mid-management level, while only 5% were college or university faculty. Almost 17% of the panel members were located outside the United States. Their self-rating of the level of expertise in the field of lean manufacturing ranged from medium to very high, with the majority rating themselves as having a high level of expertise. Moreover, a large number of experts had a minimum of 6 to 10 years of experience related to lean.

The panel of experts participated through three iterations of Delphi questionnaires in both hard copy and electronic format, rated competency areas, and offered many valuable comments. Additional competency areas suggested from the pre-Delphi study were added to the Round One questionnaire. The three rounds of the study had response rates of approximately 73%, 79%, and 75%.

Table 2 contains results based on the additional questions asked regarding the importance and overall quality of the study in the Round Three questionnaire. The majority of the Delphi panel experts indicated that the results of this study were either of very high or high importance to the field of lean manufacturing. Moreover, most responses rating the overall quality of the study ranged from very high to high.

Table 2: Results on Importance and Overall Quality of the Study from Round Three

	Very High 5	*High 4*	*Medium 3*	*Low 2*	*Very Low 1*	TOTAL
Importance of the results of this study to the field of lean manufacturing	36%	*57%*	2%	3%	2%	53
Overall quality of study	32%	*51%*	15%	2%	0%	53

Sample of qualitative responses obtained on the importance and/or quality of the study are listed below:

- "As a lean practitioner over the past 6 years, not having a valid certificate demonstrating proficiency in lean is a drawback. The industry needs an effective method to document and certify individuals, and this study will enable a robust standard to be set."
- "This study was well-developed and was very comprehensive. This is a good model for overall business planning and execution."
- "This study is an important step in validating BOK. "
- "My interest in this survey/study has greatly increased since my professional developmental goal for this year is to obtain a lean certification!"
- "I feel the study was prepared very well and complete."
- "The study is the most comprehensive that I have ever seen in my career. I hope that it will serve to standardize and further lean principles beyond the current narrow-minded focus of cost cutting..."

A list of prioritized competency areas for lean Bronze level examination based on mean and standard deviation scores is given in Table 3. The competency areas have been grouped under each domain and are categorized by low and high standard deviations. The competency areas in bold with asterisks (*) represent a high mean and low standard deviation (higher degree of consensus among panel members), and those not in bold represent a lower degree of agreement among panel members with either high or low mean values. Y% represents the "Yes" percentage of responses obtained from the "Necessary for Certification Exam?" question.

Table 3: Prioritized list of Competency Areas from the Lean Bronze Certification Level

Competency Areas	Mean	SD	Y%
I. ENABLERS FOR LEAN			
***1.1.4. Principles of lean leadership**	**3.96**	**0.187**	**100**
***1.2.6. Ergonomic, clean and safe work environment, and results**	**3.79**	**0.453**	**98.2**
***1.1.5. Lean corporate culture**	**3.09**	**0.405**	**96.2**
1.2.3. Teamwork	2.39	0.685	92.3
***1.2.2. Employee training and development**	**2.21**	**0.559**	**81.8**
1.2.1. Principles of empowerment	2.21	0.674	82.1
***1.2.4. Suggestion/Feedback/Appraisal System**	**2.05**	**0.553**	**81.8**
***1.1.3. Long and Short-term Planning**	**2.04**	**0.499**	**81.5**
1.1.1 Business vision, mission, values, strategies and goals, including resource allocation	1.95	0.61	15.8
Motivation Theory	1.75	0.714	10.7
1.1.2. Respect for Humanity and Social Responsibility	1.29	0.731	9.1
Socio-technical Systems	1.18	0.601	5.5
1.2.5. Employee Turnover, Absenteeism and Compensation	1.14	0.718	1.8
II. LEAN CORE OPERATIONS			
***2.4.3. Cellular and Continuous Flow**	**3.93**	**0.26**	**100**
***2.4.2. Just-in-Time Operations**	**3.91**	**0.29**	**100**
***2.4.1. Systematic identification and elimination of waste**	**3.91**	**0.348**	**98.1**
***2.4.4. Lean Tools for Continuous Improvement**	**3.86**	**0.398**	**100**
2.3.1. Suppliers	2.23	0.708	23.2
***2.1.1. Operational Vision and Strategy**	**2.04**	**0.533**	**10.7**
2.2.1 Product Design and Development	2.04	0.731	27.3
Facilities Design and Layout	1.91	0.606	25
Six Sigma/Problem-solving Techniques	1.84	0.682	14.5
Quantitative Decision-making Techniques	1.78	0.686	15.1
2.3.3. Distribution and Transport Alliances	1.77	0.572	7.3
2.3.2 Customers	1.4	0.776	14.3
2.2.2. Product Market Service	1.21	0.647	7.1
Optimization Techniques	1.18	0.71	5.4
Simulation Technique	1.14	0.743	7.3

Table 3 (continued): Prioritized list of Competency Areas from the Lean Bronze Certification Level

III. BUSINESS CORE OPERATIONS – SUPPORT FUNCTIONS	Mean	SD	Y%
***3.1.1 Administrative Vision and Strategy**	**2.07**	**0.563**	**83.9**
Supply Chain Logistics	1.91	0.64	7.3
3.1.2. Alignment, Systematic Business, and Service Process Design	1.86	0.616	5.5
Materials Requirement Planning (MRP)/Enterprise Resource Planning (ERP)	1.8	0.737	9.4
Lean Accounting	1.34	0.769	9.1
IV. QUALITY, COST & DELIVERY MEASURES			
***4.1.1 Quality Results**	**3.8**	**0.447**	**100**
***4.2.1 Cost and Productivity Results**	**3.77**	**0.632**	**98.2**
***4.3.1 Delivery and Customer Service Measurement**	**2.79**	**0.594**	**89.1**
Quality Management System (QMS)	1.96	0.719	14.8
International Organization for Standardization (ISO) and Lean	1.79	0.706	7.3
V. BUSINESS RESULTS			
Lean Business Metrics	1.96	0.533	41.1
5.1.1 Customer Satisfaction Results	1.96	0.687	12.7
5.2.1. Profitability Measurement	1.4	0.743	18.9
Total Supply Chain Cost	1.3	0.737	5.6

The prioritized list of competency areas obtained for the Bronze level examination indicate the important areas to be included on the body of knowledge of the lean manufacturing certification exam. A curriculum model can be designed based on these competency areas for an undergraduate level program in lean manufacturing.

Conclusion

This role delineation study was conducted to refine the body of knowledge for the SME/AME/Shingo lean manufacturing certification examinations. A Delphi technique with both qualitative and quantitative components was used to collect data, and to obtain feedback and suggestions from experts in the field of lean manufacturing. A convergence of opinion on the competency areas provided a basis for validating the body of knowledge for Bronze, Silver, and Gold levels of lean certification examinations.

It is noteworthy to recognize the high level of professionalism of the panel of experts that participated in the study exemplified through their prompt and thorough responses. The comments and ratings provided by these experts were good indicators of the fact that the study was of high importance for the lean manufacturing discipline, and that it was also of

high quality. Forty-two prioritized competency areas that emerged from the study were organized as a body of knowledge and were grouped into five major domains: (a) Enablers for Lean, (b) Lean Core Operations, (c) Business Core Operations – Support Functions, (d) Quality, Cost and Delivery Measures, and (e) Business Results. This body of knowledge serves as a model for developing an undergraduate-level curriculum in lean manufacturing.

References

[1] Dennis, P., "*Lean Production Simplified*," New York: Productivity Press, 2002.

[2] Koenigsaecker, G., "Leadership and the Lean Transformation," *Manufacturing Engineering*, November 2005, pp L7-L11.

[3] B.J. Hogan, "Lean Certification Standard Sought," *Manufacturing Engineering*, Vol. 135, No. 3, September 2005, pp 165-168.

[4] Wehrle, L., "Foundations of the Certification Program," *Contract Management*, Vol. 45, No. 3, March 2005, pp 62-65.

[5] Shah, H.A., "*A Role Delineation Study for the SME/AME/Shingo Lean Manufacturing Certification Program*," Doctoral dissertation published at Eastern Michigan University, Ypsilanti, MI, 2007.

[6] Delbecq, A.L., Van de Ven, A.H., and Gustafson, D.H., "*Group Techniques For Program Planning: A Guide To Nominal Group And Delphi Processes*," Glenview, IL: Scott Foresman and Company, 1975.

[7] Dunham, R.B., "*The Delphi Technique*," cited September 2004 in http://www.slais.ubc.ca/resources/research methods/group.htm, 1996.

[8] Jones, C. M., "*The Component Skills Of Workplace Literacy And The Utilization Of Computer Assisted Instruction To Achieve It*," Unpublished doctoral dissertation, Kent State University, 1994.

[9] Tillman, T., "*A Delphi Study To Identify Fundamental Competency Areas For Certification Testing Of Manufacturing Technologists And Entry-Level Manufacturing Engineers*," Unpublished Doctoral thesis, Purdue University, 1989.

[10] Shah, H.A., "*A Delphi Study To Develop Engineering Management Curriculum At Eastern Michigan University*," Masters' thesis published at Eastern Michigan University, Ypsilanti, MI, 2004.

Biography

HIRAL A. SHAH is an Assistant Professor in the Mechanical and Manufacturing Department at St. Cloud State University. Her primary area of teaching is in the Engineering Management program. She received her undergraduate degree in Mechanical Engineering from Maharaja Sayajirao University of Baroda, India, and M.S. and Ph.D. degrees in Engineering Management from Eastern Michigan University. She is a Certified Enterprise Integrator (CEI), Professional Engineering Manager (PEM), and a Project Management Professional (PMP).

TRACY S. TILLMAN is a retired professor from the School of Engineering Technology at Eastern Michigan University. He holds B.S. and M.S. degrees from Minnesota State University, Mankato, and M.S. and Ph.D. degrees from Purdue University.