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Lean Throughout the IE Curriculum

Abstract

In recent years, the principles of Lean Manufacturing have received a great deal of attention in industry and in the popular press. Companies seeking a workforce trained in the principles of lean often send their employees through lean certification programs. While some IE programs now offer undergraduate courses devoted to lean, some working IEs and faculty in Industrial Engineering programs have dismissed lean citing that lean principles are "just traditional industrial engineering". Lean is seen to be a new buzzword that may be expected to lose favor as did quality circles or reengineering.

In this paper we consider the lean phenomenon and summarize how it is similar to and different from "traditional" IE. We then suggest how the essential elements of lean thinking can be integrated throughout the core of an IE curriculum so that students are introduced to the essential lean principles without the need for additional courses specifically devoted to lean. We also suggest how it may be possible for undergraduates enrolled in an IE program to obtain lean certification before graduation making them more desirable to companies who are pursuing lean initiatives. Besides providing graduates with skills that are in high demand, certification can serve to emphasize the natural connection between industrial engineering and lean thinking increasing the awareness of the value of IE to an organization.

1 Introduction

Since the mid-90's, lean has been a hot topic among practitioners of industrial engineering. The annual IIE Solutions Conference features many sessions promoting lean and helping attendees learn to apply lean concepts in their jobs. IIE has held focused Lean Conferences. In San Diego, the IIE Chapter meetings featuring lean are the best attended events. Other organizations including AME, APICS, ASQ, INCOSE, and SME offer lean meeting programs. Professional organizations and for-profit groups have developed lean certificate programs. Universities also offer lean programs, but these are often offered by Schools of Business Administration, or through extension programs.

And yet few industrial engineering programs appear to formally offer training in lean principles as a part of their undergraduate programs. There are many reasons that may explain why programs eschew lean, but one common outlook was expressed by an industrial engineering faculty member who asked, "Isn't it true the 'lean manufacturing' is nothing but good old IE/OR cloaked by a new name?" [1]

These authors agree with most IE faculty that, more than graduates of any other discipline, our graduates are well-prepared to apply most lean concepts (by any name) and that the industrial engineering profession should be looked at as the natural resource for organizations who are looking to adopt lean ideas. However, while aspects of lean are "good old IE", some important lean concepts and tools are not a part of the core IE curriculum. Furthermore, we realize that many of the people who are making the decisions that their organizations should embark on the

lean journey, do not know about the relationship between IE and lean thinking. Rather than bemoan that other groups are staking claim to "our" territory, or significantly revise our curriculum to emphasize lean, we have decided to assess the principle ideas and tools of lean and incorporate them within the existing Industrial Engineering curriculum at the University of San Diego (USD). By teaching students about lean within the broader IE context, our graduates will be in a position to respond to industry demands by applying lean as required, but they will also understand that lean is just one approach to improving systems.

In the next section, we will define lean as both a "philosophy" for systems improvement, and as a set of tools used to accomplish the improvements. This will be followed by a discussion of how lean parallels the IE skills typically taught in undergraduate programs, and how it differs from these curricula. Section 3 entails a brief discussion of why we think it is important for lean to be taught within IE programs, and why it should be incorporated within the existing courses and not taught as a separate topic.

In Section 4, we will map the essential elements of lean to the IE program at the University of San Diego. Because our curriculum is a broad-based program, lean concepts can be delivered throughout the curriculum with no new courses are needed. Finally, we will present a framework by which schools could award students *Lean Certificates* attesting to their mastery of lean concepts. These certificates can serve the dual purpose of providing students with a marketable entry for their resumes, and putting industry on notice that industrial engineering programs are the logical sources for people who can improve system performance using lean and other tools.

2 Defining Lean Principles

In their book *Lean Thinking*, James Womack and Daniel Jones state that lean:

> *"... provides a way to do more and more with less and less— less human effort, less equipment, less time, and less space— while coming closer and closer to providing customers with exactly what they want."* [2]

To people trained in industrial engineering, this sounds very much like what we have done since the work of Frederick Taylor, and the Gilbreths. In fact, the lean "revolution" can be largely attributed to the well-documented successes of Toyota and the Toyota Production System. [3, 4] Although the philosophy of improving system performance by removing *muda*, or waste, is fundamental to IE, "… the developers of the Toyota Production Systems have refined and extended these classical industrial engineering tools to a level that most U.S. manufacturers only aspire to." [5] Yet, Toyota itself credits industrial engineering for many of the practices that are fundamental to its success. However, lean thinking is different than traditional IE practice in that it has as its central tenet as a focus on identifying and improving value *as seen from the eyes of the customer*. This customer-oriented focus is a critical aspect of lean because it drives the overall process of evaluating a system from a lean perspective and is the inspiration behind some important lean tools.

Having defined lean as the continuing quest to eliminate waste, many proponents of lean advocate 5 critical principles in the following procedure:

Step 1. Define *value*
Step 2. Identify the *value stream*
Step 3. Replace batch processing with *flow*
Step 4. Replace push flow with *pull*
Step 5. Strive for *perfection*

Clearly, ideas commonly taught in IE curricula are included in this procedure. Qualitative and quantitative IE skills not often learned in other disciplines are needed to achieve steps 3 and 4. Step 5 essentially acknowledges that finding the *One Right Way* is often an evolutionary process. While following this general framework, practitioners of lean apply a common set of tools in pursuit of eliminating waste and applying the general lean principles. While many of these tools are part of the standard IE toolkit, others were developed to support lean initiatives. This raises the question, "If lean and IE are similar, why make mention of lean within an IE program?"

If the goal is solely to teach people good tools and methods for improving processes, there may be little need to highlight lean. However, our graduates are going to be working with other people who do not know very much about "IE", but who have been exposed to "lean". Few IE programs emphasize the idea of customer satisfaction to the extent that it is emphasized in lean. Value is often considered to be anything that the customer would be willing to pay for. The value stream and corresponding value stream map are customer-centric representations of processes designed to help identify waste throughout the system, rather than the waste in specific processes. IEs who do not understand this perspective will have difficulty participating on teams with people from other disciplines.

Employers (especially managers without IE degrees) who have adopted lean are unlikely to understand that an IE graduate knows the essential lean ideas. Consequently, there are several strong reasons for making sure that graduates are familiar with lean principles:

- Graduates will have a common language for working with non IEs and an understanding of the value stream used by lean practitioners.
- Employers think that lean is valuable enough that they send IEs to learn it. The popularity of lean sessions at IIE conferences and meetings suggests that IEs have not fully related their coursework with lean practice.
- While "lean" might fall out of favor, the underlying IE concepts won't go away. Having served as lean change agents, our grads will be in position to help their organizations use other IE tools to improve system performance.

Even within the domain of companies practicing lean, IEs should play important roles that will only be available to them if they understand what their coworkers do about lean practices. In a response in the *Ask an Expert* column of Industrial Engineer, Merwan Mehta identified the following roles for IEs within organizations using lean to direct improvement efforts [6]:

- IEs will have to play the role of a catalyst for change.
- IEs will have to be value stream managers, leading the charge to optimize the entire value stream through participation and involvement of shop employees.
- IEs will be called upon to create value stream maps, identifying kaizens needed for achieving the future state in the value stream maps and leading the kaizen activities to achieve the future state.

- Finally, IEs will have to have knowledge in the implementation of other lean initiatives such as process improvement (Six Sigma), total preventive maintenance, setup reduction, poka-yoke (mistake-proofing), cellular flow and plant redesign, and incorporating design for manufacturing and assembly concepts into products.

There is some truth to the idea that elements of lean are simply restatements of fundamental IE ideas rephrased for the general population. That does not mean that our graduates should not know about lean. As one department chair wrote: "But the truth is packaging does make a difference, and if it allows IE to penetrate markets that it has failed to gain in the past, I applaud it loudly."[7]

3 Incorporating Lean in the Undergraduate Curriculum

For IEs to take on these roles mentioned in the previous section and have the opportunity to affect change, they must be familiar with lean terminology and tools. There are at least three ways that this can be done: 1) After graduation through lean training programs, 2) As part of the undergraduate curriculum in courses devoted to lean, and 3) By integrating lean ideas throughout exiting curriculum.

IE graduates are free to pursue any and all relevant certifications and licenses after graduation and sit right along side non IEs in the process. But to suggest that IE graduates should wait until after graduation to learn about lean assumes that we have not taught lean principles within the IE curriculum. Our students leave our programs with a significant knowledge base in lean concepts. Much of the information delivered through lean certificate programs is already contained within any traditional IE curriculum, only our students are not always told what is being covered is a "lean principle" and too often, for the students, the topics seem unconnected.

Separate courses on lean techniques may have the advantage of making the connection to lean readily apparent to our students. This also sells the knowledge acquired by packaging it with the lean name. In most cases though, there will be significant redundancy as topics are covered in both the "traditional" and the "lean" IE courses. This may strike many as wasteful and not the most efficient way to accomplish our goals. Furthermore, if topics are removed from existing courses and moved into a lean course, it is likely that students will miss the connection between lean methods and other IE techniques. Rather than teach the "5 Whys" technique in a lean course, it can easily be covered in a quality course where it can be introduced as one method used to find the root causes behind failures.

Rather than taking ideas out of our courses and reassembling the individual lean topics into a special topics course, we propose that lean concepts could be emphasized "across the curriculum". By highlighting topics already covered and inserting necessary topics into the appropriate courses within the IE curriculum we can leverage work that is already being undertaken and give our students a real advantage among those employers who actively recruit based on "demonstrated" knowledge of lean principles.

This lean across the curriculum approach provides the IE programs the added benefit of taking a slightly higher ground. The creation of courses devoted to lean principles might give the impression that the curriculum is lacking. By not adding individual courses to our curriculum, we comment upon the sufficiency and stability of our curriculum and the knowledge our students gain by completing the IE degree.

By following this approach we are able to heed the admonition of Adedeji Badiru, who wrote:

> *The core of our profession should always be industrial engineering – not supply chain, not expert systems, not lean initiatives, not TQM, and not any other exploratory offshoot. Buzzwords come and go. If we remain consistent with our name and core mission, the profession will survive with a clear and recognizable identity. But if we dabble in fad-based names that have no historical roots, we will be swept around as the sentiments change.*[8]

By explicitly referring to lean ideas as core principles of IE within the core courses of an undergraduate curriculum, students learn that much of lean is a subset of IE. Furthermore, the faculty are free to add and remove topics to courses as practices and buzzwords change without revamping the curriculum.

4 Proposal for a *Lean-inclusive* Curriculum

Before developing a proposal for a curriculum containing lean, one must first answer the question, "Which lean topics are the most important and consistent with IE?" One approach to answering this question is to look at the content in lean certificate programs offered by universities, technical societies and consulting firms. Ten lean certificate programs from across the United States were examined to determine what lean concepts are typically included in a "Lean Certificate" program. The certificate programs examined vary in length from 56 – 104 hours depending on the number of concepts with 80 hours appearing to be the norm. So a lean certificate requires approximately the same contact time as two one-semester courses.

Table 1 summarizes the 16 topics that are commonly covered by ten lean certificates. Most programs cover a subset of the sixteen concepts, with a majority teaching 6 – 8 concepts in significant detail. Consequently, there is differing opinions about what material should be included in a lean certificate program. Table 1 also summarizes the how the topics fit into most IE curricula. There is a core set of eight topics that are likely included in some course in most IE programs. These are the lean topics that are most closely aligned with traditional IE. Most of these topics have been included in IE curricula for many years and it is only necessary to make the connection between the IE content and the lean vocabulary.

Another set of four topics can be easily added to many classes without requiring extensive revision. These topics are more likely to be included in an IE program elective, or might require a new set of lectures to be added to a course. For example, Value Stream Mapping might be included in any course where student learn how to describe a system and identify opportunities for improvement including *Intro to IE*, *Systems Engineering*, *Senior Design*. Finally, there is a set of four topics that are beyond the scope of most IE curricula. These are generally managerial

topics related to how lean is introduced into an organization. Although they are appropriate topics for elective courses in management engineering, they fit less well with the IE core.

Table 1: Summary of Lean Topics Included in Ten Lean Certificate Programs

Topics Included in Most IE Programs	Topics Easily Added to IE Curricula	Topics Outside the Scope of Typical IE Curricula
• Team Building	• Lean Supply Chain Management	• Overview of Lean Enterprise
• 5S/Visual Enterprise	• Total Productive Maintenance	• Lean administration
• Error Proofing	• Value Stream Mapping	• Lean culture/CQI Philosophy
• Inventory Management/Kanbans	• Introduction to Kaizen Events	• Lean Metrics/Incentives
• Process Cells		
• Setup Reduction		
• Standardized Work		
• CQI Problem-Solving Tools		

In fall 2005, the Society of Manufacturing Engineers (SME), the Association for Manufacturing Excellence (AME), and The Shingo Prize for Excellence in Manufacturing released the body of knowledge (BOK) for an 80-hour program leading to a *Lean Knowledge Certificate* [9] This certificate emphasizes having the skills needed to apply lean and differs from certificate programs in that places has a manufacturing orientation and has less emphasis on the managerial aspects of adapting lean across an enterprise. Consequently, the *Knowledge Certificate* most closely matches the likely responsibilities of recent graduates. The lean certificate's body of knowledge contains five modules which are listed below with the number of contact hours devoted to each area:

Module 1. Enablers for Lean (12 hrs)
Module 2. Lean Core Operations (44 hrs)
Module 3. Business Core Operations/Support Functions (8 hrs)
Module 4. Quality, Cost & Delivery Measures (12 hrs)
Module 5. Business Results (4 hrs)

Of the five modules, *Lean Core Operations* includes the topics that most IEs are likely to use early in their careers, though each of the modules includes topics typically found in IE curricula (e.g. material management and the cost of quality). The appendix summarizes 69 specific topics identified in the BOK for Module 2. Most of the topics included in the 10 lean certificate programs are contained in this module. Because of its relevance to applying lean principles in practice, and our mission of preparing graduates for success in their first years on the job we focused on Module 2 when assessing the extent of lean coverage in our program.

The Industrial and Systems Engineering (ISyE) program at USD is a "general IE" program that has students taking courses in all areas of IE with no special emphasis. The fifteen junior and senior level courses with seven labs provide students with a wide breadth of IE knowledge which naturally introduces many lean topics (under a variety of names). To assess the extent of our lean coverage, the authors assessed each ISyE course to determine the extent to which we currently cover the 69 topics listed in SME/AME/Shingo Module 2. The results are summarized in the appendix. Only those courses that currently include some coverage of a lean topic are

shown. An entry of "1" in the table indicates that the topic is currently included in the course, though in some cases it may not be mentioned that the topic is considered by some to be a lean topic. A "2" indicates topics which we may not include in our courses right now, but which fit naturally into one of the courses we offer. It also includes topics that are discussed briefly in the indicated course with more thorough coverage elsewhere. For example, the role of a bill of material as a source of planning information is covered in the facilities course, but they are covered in more detail in the production planning course. A "3" denotes that the material is not currently covered in the indicated course, that we would be unlikely to include it into the regular content of the required course, but that that content *could* be included in a similarly named course at another school.

This analysis revealed that approximately 65% of the Module 2 concepts are already well-covered in the IE program courses and that another 23% of the topics are consistent with program objectives and can be adopted with few courses changes. The analysis also shows that some topics are covered in more than one course. In many instances this overlap is appropriate as the topics may be covered in more depth in later courses. In other cases, the courses may be unnecessarily repeating information. The program is currently assessing these topics to see whether we can coordinate classes more effectively. This could free some time allowing some of the topics denoted with a "2" to be included.

This analysis supported our belief that the coverage of lean topics in the IE program substantially prepares students for practice in industry and that more complete preparation could be obtained by introducing just a few topics and by emphasizing that many IE principles have lean counterparts. Furthermore, this analysis suggested that the coverage of lean topics in our curriculum is comparable to that provided in external Lean Certificate programs that industry recognizes as providing value; even among organizations that don't recognize the intrinsic relationship between IE and lean.

5 Providing Lean Certification

After examining their curriculum and the body of knowledge that is included in many lean certificate programs most IE programs would conclude that their students already acquire the knowledge that would garner a lean certificate if completed outside of the undergraduate degree program. At this point it may be appropriate for the school to develop a lean certificate for its students. Lean certification would add to a student's resume by attesting the student has knowledge in terms that are well-accepted by industry. It would also likely carry more weight than the listing of a single course in lean.

There are several different approaches that could be used to determine what certificate should be conferred. For example, a school with a curriculum similar to USD's could decide to confer a *Lean Methods* certificate to students completing the IE program. This certificate might indicate that the graduate knows how to apply lean tools, but has not been exposed to some of the organizational and cultural aspects that might be seen by participants in a *Lean Enterprise* program. Schools electing to supplement their core curriculum with a specific course in lean could emphasize these organizational topics, include a project and award a *Lean Enterprise* certificate.

Regardless of the scope of the certificate the school might confer the certificate to all students who pass the requisite courses, or the school could make the certificate more selective by requiring stating that students must pass all of the courses with minimum grades. It may also be appropriate for the school to partner with an outside agency (e.g. SME/AME/Shingo or IIE) who would administer a standard exam to the students that could attest to mastery of the required material.

Some people might object to the idea that a certificate should be awarded to students who are already receiving the B.S.I.E. degree. It might appear to be suggesting that the B.S. degree is less important and only has value when supplemented by a lean certificate. Consequently, the authors propose that the certificate be treated separately from the B.S. degree. The certificate should be awarded at the completion of the last course containing required lean content, or upon completion of a lean exam. If this occurs before graduation, the student will be able to list the certificate on their resume as they look for a job. This practice will also reinforce to students that lean is not "good old IE/OR", but rather that it includes only a subset of the important IE skills and tools and that it represents a portion of the value IE graduates will bring to their organizations.

6 Conclusion

Throughout industry there is little recognition that most lean concepts are a subset of the ideas taught in IE programs. There is little that IE programs can do to overcome this problem of perception other than to graduate well-prepared students who use lean as one approach to improving systems. There is also no question that recent graduates of IE programs acquire the essential skills needed to act as lean change agents. The question of whether IE programs should teach lean shouldn't be raised; we already are teaching it. In many cases all that is missing is a direct connection between IE principles and lean vocabulary.

There is also no question that many people that apply lean do not relate lean to IE; particularly corporate officers and service sector organizations. Because of the congruence between content included in lean certification and the IE curricula it is clear that many IE graduates would be well-served by receiving a lean certificate that attests to their mastery in this one area of IE. The value of the certificate is not because the certificate is the best descriptor of their knowledge, but that it is a currency that is easily understood by non-engineers who will work alongside the IEs.

This is not to say that IE programs can get something for nothing and should insert a lean certificate with the diploma. If an IE program wishes to provide for its students the advantage of being lean certified, the program needs to research the available lean certificate programs, examine the topics and contact hours required, and devise a plan to bring its curriculum in line with this training. Then the proper certificate should be issued commensurate with program content and industry norms.

Lean certification would add to the students resume by emphasizing concepts students are already leaning. This approach has the further reaching approach of educating industry on the

importance and value of the IE curriculum and the potential value IE graduates can add to an organization.

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Appendix

Comparison of USD ISyE Course Coverage to Body of Knowledge for Module 2 of the Proposed SME/AME/Shingo Lean Knowledge Certificate

SME/AME/Shingo Module 2 Topic	University of San Diego ISyE Course									
	Probability and Statistics	Work Design	Intro. To Systems Engr.	Statistical Process Control	Manufacturing Processes	Manufacturing Systems	Production Planning	Design of Experiments	Human Factors	Facilities Planning
Product Design and Development (product/service)										
Quality Function Deployment (QFD)				**1**		**2**		**3**		
Concurrent or Simultaneous Engineering					**2**	**1**				**2**
Variety Reduction						**3**				
Engineering Changes					**1**		**1**			
Design for Manufacture and Assembly					**2**	**1**				
Design for Product Life Cycle (DFx) (cradle to cradle)			**2**		**2**	**2**				
Failure Mode and Effects Analysis			**2**	**1**	**3**	**3**				
Life Cycle Engineering			**1**							
Production Process Preparation (3P)		**2**			**2**	**2**				
Knowledge Transfer Methods & Practices			**2**							
Product Market Service										
Customer Feedback and Market Needs Analysis			**1**							
Customer Specs and Requirements			**1**							
New market development and current market exploitation			**3**							
E-commerce systems			**2**							
Benchmarking			**1**							
Suppliers										
Supplier Development Processes							**2**			
Supplier Certification							**2**			
Supplier Benchmarking							**2**			
Supplier Satisfaction Measures							**2**			
Corrective Action System							**2**			

1 = Currently covered in USD course
2 = Appropriate for USD Course, but not currently included, or currently included without detail
3 = Could be taught in USD course, but no intention to include at this time

Comparison of USD ISyE Course Coverage to Body of Knowledge for Module 2 of the Proposed SME/AME/Shingo Lean Knowledge Certificate (cont.)

SME/AME/Shingo Module 2 Topic	University of San Diego ISyE Course									
	Probability and Statistics	Work Design	Intro. To Systems Engr.	Statistical Process Control	Manufacturing Processes	Manufacturing Systems	Production Planning	Design of Experiments	Human Factors	Facilities Planning
Customers										
Customer Training and Development Processes							**3**			
Customer Selection and Focus							**3**			
Demand Load Leveling							**3**			
Corrective Action System							**3**			
Distribution and Transport Alliances										
Warehousing										**1**
Distribution Centers										**1**
Cross-Docks										**1**
Reverse Logistics (returns, dunnage, etc.)						**3**	**2**			
Remanufacturing / Maintenance, Repair and Overhaul						**2**	**2**			
Just-in-Time Alliances						**3**	**2**			
Supplier Managed Inventory Systems						**3**	**2**			**2**
Systematic identification and elimination of waste										
Waste Identification and Elimination (7+ wastes)		**1**								
Value Stream Mapping		**3**	**1**							**2**
Value Analysis		**3**	**1**							
5S Standards and Discipline		**2**							**2**	**1**
Visual Workplace		**1**							**1**	**1**
Kaizen Blitz Events		**3**		**2**						**3**
Mistake / Error Proofing (Poka-Yoke)		**1**		**2**	**1**				**1**	
Quality at the Source / Source Inspection				**1**						
Continuous Improvement (Kaizen)		**1**		**1**						
5–Why's Problem Solving		**3**	**1**	**1**						

Comparison of USD ISyE Course Coverage to Body of Knowledge for Module 2 of the Proposed SME/AME/Shingo Lean Knowledge Certificate (cont.)

SME/AME/Shingo Module 2 Topic	University of San Diego ISyE Course									
	Probability and Statistics	Work Design	Intro. To Systems Engr.	Statistical Process Control	Manufacturing Processes	Manufacturing Systems	Production Planning	Design of Experiments	Human Factors	Facilities Planning
Just-in-Time Operations										
Takt Time		1				1				1
Material Signals (Kanban)							1			
Pull System		1					1			
Continuous Flow							1			1
Just-in-Time (JIT)							1			
Quick Changeover/Setup reduction (SMED)						1				
TPM						1				2
Load-Leveling (Heijunka)							3			3
Cellular and Continuous Flow										
Cellular Manufacturing		2				1	2			1
One Piece Flow		2				1				2
Standard Work (operator instructions, etc.)		1			1					
Multi-Process Handling						2				2
Autonomation (Jidoka)						1				
Production Schedule							1			2
Bills of Material							1			2
Routings							1			2
Flow Analysis Charts (spaghetti diagrams)							1			2
Lean Tools for Continuous Improvement										
Plan-Do-Check-Act (PDCA) (DMAIC)		1		1						
Reliability and maintainability			2	3		2				
Root Cause and corrective action				1						
Flowcharting		1	1	1			2			
Pareto		1		1						
Cause and effect diagrams (Fishbone)		1		1						
Check Sheets	1			1						
Histograms	1			1						
Scatter and Concentration Diagrams	1			1						
Control Charts (includes SPC)		2		1						
Problem Solving Storyboards				3						