Chapter 1

How Lean Transformed the Career of an Industrial Engineering (IE) Faculty

An Incomplete IE Education

From 1978-1983, I studied for my B. Tech. in Mechanical Engineering at the Indian Institute of Technology (Chennai). Next, from 1984-1986, I studied for my MS in Industrial Engineering (IE) from the University of South Florida. Finally, from 1986-1990, I studied for my Ph.D. in IE at The Pennsylvania State University. In 1990, I began my career as an Assistant Professor at the University of Minnesota. The timeline for my IE education shows that I did not work in industry between any of my academic degrees!

My First Introduction to Lean

From 1990-1999, I religiously fulfilled the obligations of a faculty in academia at a top-tier research university by teaching, doing research, obtaining funding to support my research team and publishing papers in academic peer-reviewed journals. In 1999, on the recommendation of Prof. Blaine Lilly, a faculty colleague in the Department of Integrated Systems Engineering at The Ohio State University, I read the business bestseller about the Toyota Production System – *Lean Thinking* (Womack, J.P. and Jones, D.T. 2010, Simon & Schuster, ISBN 0743249275). The book is written by management consultants who do not have any IE degrees. Still, *Lean Thinking* opened my eyes that the Toyota Production System (TPS) embodies a different IE that was not taught in the IE textbooks we were using at that time, as well as the undergraduate curriculum of my department.

Being an Irrelevant Engineer (IE) instead of Industrial Engineer (IE)

On the teaching front, I was teaching IE courses using textbooks that taught the archaic IE instead of the IE for the Toyota Production System (TPS). The academic curriculum emphasized Operations Research courses with limited real-world application. Yet every year the department was graduating anywhere between 80-100 IE undergraduates who entered industry! And on the research front, my situation was even worse. I was doing nothing to replace the manual pencil-and-paper tools that IE professionals were using to implement Lean.

The Research Grant that Began my Lean Transformation

In 2001, with the help of another faculty colleague and my mentor in the ISE department, Prof. Rajiv Shivpuri, I received a research grant from the Defense Logistics Agency (DLA). My project was one of several projects in the portfolio of the Forging Defense Manufacturing Consortium (FDMC) that was managed by the Advanced Technology Institute (ATI)[1] from 2001-2008. The goal of the consortium was to assist custom forge shops to reduce lead times for the forgings that they supply to the DLA to maintain critical weapon systems.

The goal of my research project titled *Flexible Factory Design* was to develop the science and tools for adapting Lean for high-mix low-volume (HMLV) manufacturers. In

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[1] SCRA Applied Technologies (www.SCRA.org)

particular, I was expected to help the small to mid-size high-mix low-volume (HMLV) forging job shops. Lean is based on the Toyota Production System (TPS). In contrast, the assembly line is a low-mix high-volume (LMHV) manufacturing system. The job shop and assembly line lie at the opposite ends of the spectrum of manufacturing systems! Therefore, I coined the buzzword "JobshopLean" to distinguish my work from Lean but also give full credit to Lean.

ATI's Stipulation Concerning Funding

Unlike a funding agency like the National Science Foundation that supports theoretical research, my sponsor had a very strict stipulation. *They would renew funding every year **if and only if** I demonstrated that industry was implementing my research and realizing tangible benefits from doing so*. That stipulation made it really hard for me to get industry cost share to support my grant in the first couple of years. Initially, when I contacted custom forge shops if they were interested in implementing JobshopLean, several cast aspersions on my research as being "too academic". I had no track record of successfully implementing JobshopLean! So, to get the industry cost share, I created a comprehensive program for industry outreach and engagement that (i) incorporated the IE for implementing JobshopLean in several courses, (ii) implemented my teaching philosophy that every course should have a team-based industry project and (iii) utilized the PFAST (Production Flow Analysis and Simplification Toolkit)[2] software that my research team developed to support students doing co-curricular projects or internships in industry.

The Beginning of the End of my Academic Career

In 2004, I decided to commercialize the "product" that my research team had developed viz. the PFAST (Production Flow Analysis and Simplification Toolkit) software.

Unfortunately, the department cautioned me that I was not being paid to commercialize my research. I was supposed to focus on securing research funding and publishing papers in academic peer-reviewed academic journals.

Also, I proposed to fund my research by incubating a business on campus that was based on further development of software tools like PFAST that would support delivery of consulting services offered to high-mix low-volume manufacturers. Again, the department cautioned me that funding obtained from industry was "low-grade" compared to a grant from, say, the National Science Foundation.

Plus, the technology commercialization office at The Ohio State University was going through a major reorganization at that time. So there was no help in market assessment from that office!

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[2] PFAST (Production Flow Analysis and Simplification Toolkit) helps to analyze and simplify the complex material flow network that exists in any job shop that desires to implement Lean. A job shop easily produces hundreds, sometimes thousands, of components with different manufacturing routings. Different combinations of PFAST outputs are used to implement strategies to simplify the material flows, such as purchase of flexible automation, product mix segmentation, implementation of stand-alone cells, revision of manufacturing routings, rationalization of the product mix, etc.

However, it turned out that I was the biggest barrier to the success of my commercialization plan. Here was I telling others to buy and use my software. *But I myself could not point to a single client that I had personally helped to implement JobshopLean using the PFAST outputs.* How could I? Being a full-time IE academic who could do at most one day of consulting every week per the university rules, I was in no position to invest that much time to work with a single manufacturer!

Salvation At Last!

Hannes Hunschofsky, the President of Hoerbiger Corporation of America had heard about my JobshopLean research from colleagues who had presented at the 2011 JobshopLean Conferences. In 2012, I was offered the job of Director of IE Research. I had to demonstrate that JobshopLean was a viable manufacturing strategy that could be implemented in their high-mix low-volume manufacturing facility in Houston, TX. Never had I done this in the 22 years that I had been an IE academic! But here was a chance to implement my research in industry. I quit my faculty job to start in my first-ever job working as an IE (Industrial Engineer) in industry. I was responsible for discovering, justifying and implementing each and every IE improvement that would improve a high-mix low-volume (HMLV) manufacturing facility.

Work Experience = Time + Successes + Failures

Working as a full-time IE gave me the industry experience I never had. Unfortunately, it takes time to get experience in advising others to improve the work they do and the systems they manage. Change is threatening to everybody except the person proposing it, unless he/she leads the change from start to finish. For example, compared to implementing 5S, implementing a manufacturing cell and asking upper management to grant the cell team the autonomy to manage their cell is radical change. There is a reason why most Lean implementations are undertaken as a continuous series of small improvement projects (aka *"kaizen"* which is Japanese for *Continuous Improvement*). Change needs to happen as a series of non-threatening modifications in a business that produces tangible improvements that an executive (or executive team) can see.[3] Nobody teaches this to the faculty in any IE department!

The Result of Getting Work Experience

JobshopLean is a viable approach for adapting Lean in any small and mid-size high-mix low-volume manufacturing facility. I developed it over the course of the 10+ years when I did the necessary research, teaching and industry outreach at The Ohio State University. But, while in the cocoon of academia, I knew little about the challenges of convincing industry practitioners to implement ideas that flew in the face of Lean. It was only after leaving academia in 2012 have I experienced the difficulties of implementing JobshopLean in the last 3+ years. It takes a lot to implement even a simple improvement idea! Many problems in industry do not take advanced optimization methods and software to solve. Instead, when the time comes to implement an idea borne of academic research, it takes patience and humility combined with sustained and dogmatic effort.

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[3] Perhaps the biggest difference between academia and industry is that it may be okay to challenge peers in academia, say at a conference or in a journal paper. But, it is a minefield when dealing with executives who run a for-profit business.

Usually that means being onsite at a client site for 1-2 days every week working on project teams, either as a member or a leader, training employees and supervising IE interns that the client agreed to hire for supporting the different project teams.

Looking to the Future

I cannot get back the 22 years of my career that were spent in academia during which period I had little meaningful interactions with industry. But at least today I am working in industry as an Industrial Engineer and leveraging my past research to be both a problem-solver and change agent! I hope to return to teaching part-time in an IE department but leave one foot firmly in industry.

A Dedication to My Teachers

It was my parents and family who encouraged me to pursue a Ph.D. and pursue an academic career. But, it was also certain professors who had a lasting impact on my career path.

It was at the Indian Institute of Technology (Chennai) that the combination of these courses – *Manufacturing Technology I*, *Manufacturing Technology II* and *Introduction to Operations Research* – first got me hooked on my future career. It fascinated me that manufacturing facilities could be modeled, evaluated and improved using quantitative methods. Then there was the research of Dr. S. Rajesham (Group Technology and Cellular Manufacturing), Dr. T.T. Narendran (Simulation of Inventory Systems) and Dr. R. Rajagopalan (Part Family Formation for Group Technology using Graph Theory) that kindled my interest to pursue graduate studies. Despite not knowing much OR (Operations Research) in my undergraduate days, I dared to thumb through the Proceedings of the IMTDR (International Machine Tool Design and Research) Conference and CIRP Annals, fascinated by the use of quantitative methods for flexible machine tool design, for machining path planning, for manufacturing cost estimation, etc.

At the University of South Florida, it was Prof. Jim Chrissis, Prof. Suresh Khator and Prof. Del Kimbler who reinforced my desire to pursue doctoral research on practical applications of OR in the manufacturing.

At Penn State, it was my dissertation co-advisors, Prof. Tom Cavalier and Prof. Paul Cohen, who patiently allowed me to pursue a research idea that bridged Operations Research (OR) and Manufacturing Processes. In addition, I will always cherish the memory of Prof. Inyong Ham, the "Godfather of Group Technology". Never in my life had I taken a course like the one that he taught on Manufacturing Systems! The workload and expectations in his course were brutal. *He expected us (students) to find a local company to sponsor the semester-long project for his course.* For our industry project, we had to apply what he taught in the course to solve appropriate problems we discovered at that company. Naturally, I cussed and grumbled at that time. Not only did I survive that course but I gained the confidence to *integrate* ***and*** *apply* OR to solve real-world problems in industry. Later in my own career, I ended up having that same project component in all the courses that I taught!

Appendix 1

"Textbook IE" versus "Toyota IE"

This Appendix compares and contrasts the IE that is taught today in IE departments with the IE that was pioneered by the world's largest automaker and has been extensively adopted throughout the world. Table 1 contrasts the IE that is taught in contemporary textbooks with the IE being practiced at/by Toyota.

Table 1 "Textbook IE" versus "Toyota IE"

IE taught in Textbooks	IE practiced at Toyota
• OR (Operations Research) model is taught without explanation of what it takes to obtain the values for coefficients, upper and lower bounds, assumptions that may compromise the feasibility of implementation in industry, etc. • OR model makes assumptions and simplifications in the actual problem in order to realize a solution • OR model is taught out of an academic textbook with no case studies to demonstrate industrial application of the models	• Projects that are done are those which company leadership understands and supports ("I'd rather do what I understand instead of what is too complicated and costly to implement") • As the developer of the solution/s, be sure to work side-by-side with employees who will be affected by the solution/s and ensure that they accept/implement the solution/s • It is okay to solve many small problems for which radical changes will not be necessary • It is okay if no OR (Operations Research) was used to solve the problem
Students are recommended to go to the College of Business for courses on Lean Leadership, Change Management, Culture Change, Workforce Motivation, etc.	• Know, or at least be acutely aware of, the importance of soft skills to effect change • Gain acceptance for one's ideas by building trust among employees that changes will not be harmful to them
• Learning happens almost exclusively in the classroom • Industry relevance of course material is primarily delivered with, for example, Harvard Business Review case studies • Industry projects in a course are viewed by students as "being too much work" • Co-ops and internships never have faculty engaged and partnered with the students • The Senior Capstone Design project, which is done at the end of the program of study, is usually the only time when learning occurs by engagement with industry	• "Stand on the X" for hours and watch work being done in the area where improvement is sought • Go talk to the employees to find out the problem's and their root causes on one's own • See for yourself, learn for yourself • Work, and problems related with doing it, is best learned by doing it oneself
• Industry experience is not a requirement to teach IE courses • Not even an engineering degree, let alone an IE degree, is a requirement to teach IE courses • Faculty with Ph.D.'s in Mathematics, Physics, Statistics and other non-Engineering disciplines are hired as IE faculty • Sabbatical leave is rarely taken to gain industry experience	• Having the ability to work side-by-side with line workers and supervisors is essential • Engage with employees and encourage them to implement their ideas for improving the product/s they make, the equipment and tools they use, the workplaces where they spend their entire day, etc.

Course on Methods Analysis and Time Studies	
Methods Analysis is an afterthought in the core IE curriculum	• Any and all work can be decomposed into value-added, non-value added and necessary-but-non-value-added elements • Cost reductions that do not eliminate employees can be achieved simply by eliminating the Seven Types of Waste in the entire organization • The ability/skill to recognize the Seven Types of Waste is best learned from co-ops, internships and industry projects (at least never solely in a classroom)
Methods Analysis is done using archaic methods such as Flow Process Charts and Man-Machine Charts	Methods Analysis is done using more effective tools such as Value Stream Mapping, Standard Work Instructions and 3P (Production Preparation Process)
Course on Facilities Planning	
The leading textbooks do not have a single case study to demonstrate that subject matter in them has practical application	• Teach the OR (Operations Research) underlying the manual Lean tools such as Value Stream Mapping, Spaghetti Diagrams, U-shaped cells, Water Striders, etc. • Term project for a course requires that students do a team-based project in industry where they must demonstrate how they applied what was taught in the course
Course on Production Planning and Control	
The Economic Order Quantity (EOQ) model for inventory control is taught as a calculus problem	• There is no need for this inventory model • Utilize setup reduction to make setup time (and cost) insignificant when making lot size decisions • Make To Order policy --- Do not batch produce assuming significant setup time and put excess inventory in stock
The Economic Production Quantity (EPQ) model for inventory control is taught as a calculus problem	The Economic Production Quantity (EPQ) model for inventory control provides the science underlying the ultimate goal of Single Piece Flow in any work environment
Material Requirements Planning is taught	• Generate a level-loaded mixed model production plan • Design flexible lines with minimal setup change times to adapt to product mix changes
• Heuristic scheduling of job shops with zero transfer delays • Finite Capacity Scheduling • ERP (Enterprise Resource Planning) • MES (Manufacturing Execution Systems)	• Reduce the large job shop to a network of smaller autonomous work cells • Utilize rough-cut shop loading strategies such as Drum-Buffer-Rope, 2-bin Kanban locations, Bottleneck Loading, etc. • Have morning huddles with employees to assign job priorities • Allow fire-fighting and expediting as long as the customer is happy • Customers do tolerate tardiness, suppliers will dictate delivery dates, machines will fail,

	employees will fall sick • It is amazing what good supervisors and cooperative employees can achieve when they are challenged by management to "move heaven and earth"
Every possible OR (Operations Research) optimization approach – Traveling Salesman Problem, Queuing Theory, Mixed Integer Programming – has been used to schedule and sequence jobs on the single capacity-constrained machine	• Show how setup reduction and product variety reduction help to minimize the need for setup-dependent sequencing of jobs
• Lot sizes are based on queuing theory (which implicitly assumes batch production) • Schedules are generated in a back office away from the shop floor	• Design the layout to place consecutive pairs of work centers in close proximity with each other • Production rate of "supplier work center" is controlled by "customer work center" using physical or electronic signals (kanbans) • Visual monitoring of buffer inventories between work centers • "Go See" scheduling to replenish on-hand inventories of different products (like when the cooks in the kitchen come out to replenish food in various dishes at a Chinese buffet)
• Mfg. Processes course is absent from the core curriculum • Mfg. courses offered in other departments, such as Mechanical Engineering and Materials Science, do not cover the topics of interest to IE's	• Add the Mfg. Processes course back into the curriculum • Add a second course – Mfg. Eng. – that teaches IE-related aspects of Lean such as standardization, setup reduction, error-proofing, Autonomation, Total Productive Maintenance, right-sized equipment, 3P (Production Preparation Process), etc.
Powerpoint presentations are the de facto mechanism for reporting on any project	• A3 Report format is used for succinct project reporting • Powerpoint slides are presented only if and when more details are needed

Appendix 2

Literature that Describes Projects where PFAST was Successfully Used

This Appendix lists some of the trade journal articles that discuss different projects on Facility Layout and Cellular Manufacturing that my students at The Ohio State University did in industry that involved the use of the PFAST (Production Flow Analysis and Simplification) software.

Zhou, J. & Irani, S.A. (2000, June). Cochran, D.S. & Tapia, C.F. (Eds.). *Design of modular layouts for fabrication-based assembly facilities*. Proceedings of the Third World Congress on Intelligent Manufacturing Processes & Systems, MIT (Cambridge, MA) and the International Institution for Production Engineering Research (CIRP), 62-69.

Marchwinski, C. & Irani, S.A. (2001, March). *Software solves identity crises for parts from big "families"*. Lean Manufacturing Advisor, 3-7.

Khaswala, Z. & Irani, S.A. (2001, September). *Value network mapping: Visualization and analysis of multiple flows in value stream maps*. Proceedings of the Lean Management Solutions Conference, IIE and University of Missouri-Rolla, St. Louis, MO, 47-63.

Huskonen, W. (2003, January/February). *Thinking Lean at TECT Cleveland*. Forging, 16-19.

Marchwinski, C. (2003, May). *Understanding families is key in high-mix low-volume facility*. Lean Manufacturing Advisor, 4-5.

Irani, S.A., Zhou, J. & Huang, H. (2003, November). *A pattern recognition approach for manufacturing facility compaction by machining function combination using flexible manufacturing modules*. Transactions of the ASME Journal of Manufacturing Science and Engineering, 125, 740-752.

Huskonen, W. (2004, March/April). *Wringing out waste*. Forging, 4.

Huskonen, W. (2004, March/April). *Ulven Forging succeeds with Jobshop Lean*. Forging, 26-28.

Huskonen, W. (2004, March/April). *Jobshop Lean workshop is a winner*. Forging, 30.

Sabri, S. & Shayan, E. (2004). *Lean strategies for furniture manufacturing*. Proceedings of the Fifth Asia Pacific Industrial Engineering and Management Systems Conference, 31.18.1-13.18.8.

Heston, T. (2010, November). *Another day, another economic recovery*. The Fabricator, 52-54.[4]

Danford, M. (2010, November). *From job shop chaos to Lean order*. Modern Machine Shop, 60-67.[5]

[4] Quoting from the article, "Several years ago …several dozen IE students (were) sent to Ometek Inc., a fabrication jobshop located in Reynoldsburg, OH, for a taste of high-mix low-volume manufacturing…Fast learners, the students ultimately helped Ometek revamp its shop layout for fast material movement. For instance, in the press brake area, they rearranged the machines into a rectangle, with WIP and tooling in the center. Parts enter and exit in one place, and operators needn't walk to reach everything they might need during a shift".

[5] Quoting from the article, "Classic Lean Manufacturing principles are practically taken as gospel, but benefits can be elusive for manufacturers that produce a variety of work in low volumes. The G&G Manufacturing Co., a family-owned precision machine shop located in Cincinnati, OH, took a different approach to Lean – one aided by software that helped identify a more efficient machine layout based (on) patterns in part routings…Organizing parts into process families and implementing hybrid cells to streamline routings has fundamentally transformed G&G's business … (It) has led to lead time improvements ranging from 40-50% and productivity improvements ranging from 20-25%, depending on the job".

Appendix 3

Results Delivered to Small and Medium Enterprises (SME) by OSU[6] Interns

This Appendix lists results that were officially reported by some of the companies that hired interns from The Ohio State University to implement JobshopLean.

- *Bula Forge & Machine, Inc. (Cleveland, OH):* The project reduced idle time on a constraint work center by 8 hours, eliminated excess work-in-process valued at approximately $130,000 and reduced average flow time for orders placed for a key part from 30 days to 12 days.

- *TECT (Cleveland, OH):* The project delivered a new layout for their facility that reduced floorspace requirements which reduced their annual facility leasing costs by $350,000. Also, the production lead times for forging large fan blades installed in high bypass gas turbine fans that are supplied to the Defense Logistics Agency were reduced by 80%-85%.

- *SIFCO (Cleveland, OH):* The project identified 32 improvement projects and convinced management to hire a full-time manager to oversee and implement Lean best practices.

- *Canton Drop Forge (Canton, OH):* The complete reorganization of the Saw department resulted in a Net Present Worth of $224, 167.

- *G&G Mfg. Co. (Cincinnati, OH):* The implementation of a flexible flow cell to produce several machined parts with similar routings yielded the following results for two of their parts:
  - Part Description: *Elbow Buddy Breather*
    - Production Hours reduced from 85 to 60
    - Manufacturing Lead Time reduced from 12 work days to 5 work days
    - Profitability increased from -13% to 19.5%.
  - Part Description: *Aurand Shaft*
    - Production Hours reduced from 100 to 65
    - Manufacturing Lead Time reduced from 16 work days to 6 work days
    - Profitability increased from -11% to 32.6%.

- *Alpha 1 Induction Service Center (Columbus, OH):* The first year's cost savings in the work cell that was implemented was $64,000 with a $20,000 investment in salaries paid to the three OSU interns hired to design and implement the cell.

- *Weber Metals (Los Angeles, CA):* The project yielded a one-time work-in-process (WIP) inventory avoidance of $3,000,000.

[6] *The* Ohio State University

- *Ulven Forging (Hubbard, OR):* The implementation of the recommended layout and investment in new equipment resulted in an annual savings of $137,000.

- *Consolidated Industries (Cheshire, CT):* Savings from various process improvements recommended by the interns helped to offset the price increases in titanium, aluminum and steel purchased by the company.

- *Trinity Forge (Mansfield, TX):* The average time to deliver a die from Storage to the Hammer it was scheduled to be used on was reduced from ~15 days to 1 day.

Appendix 4

Components of a Comprehensive Program for Service to Industry

This Appendix describes the major components of the program for industry outreach and engagement that I implemented to benefit industry throughout my teaching and research career, both at the University of Minnesota and The Ohio State University.

Figure 1 is a flowchart that describes the sequence in which I leveraged different co-curricular and extra-curricular programs of the IE department to engage with industry when I was at The Ohio State University. It allowed me to seamlessly integrate teaching and research, Lean and Industrial Engineering. Both my students and I benefitted because the interests of the companies whom we engaged were served. Despite not being employed full-time in industry, the different engagements exposed me to real-world research problems too!

Next, I describe some of the components of this comprehensive program to serve industry. Please note that the course number ISE541 corresponds to the undergraduate core course on *Facilities Planning* and the course number ISE748 corresponds to the graduate elective on *Design and Analysis of Manufacturing Systems*. In the latter course, I taught the Lean, IE and OR (Operations Research) that is used to implement JobshopLean.

Industry projects in courses: In both the undergraduate course (*Facilities Planning*) and the graduate course on JobshopLean (*Design, Analysis and Control of Manufacturing Systems*), I taught the theory and applications of the PFAST software. For both courses, I would arrange with local manufacturers to host student teams. Each student team was expected to apply what was taught in class to improve operations at the company that hosted them.

Internship program tied to my research program: I created the LEAP (Learn→Earn→Apply→Practice) Internship Program to assist manufacturers to implement JobshopLean by placing one, sometimes two, undergraduate (or graduate) interns to work onsite at their facility for 3-6 months under my supervision. This program proved to be the best mechanism to transfer my research to industry. Throughout the course of my DOD[7] grant, the talented IE interns from The Ohio State University delivered results to the custom forge shops that hired them. Please see *Appendix 3 Results Delivered to Small and Medium Enterprises (SME)* for examples of the benefits that were reported by small and mid-size manufacturers whom they helped to implement JobshopLean.

Industry workshop: I developed a workshop – *JobshopLean and Facility Layout using Production Flow Analysis* – which I taught at least once every year to interested members of the Forging Defense Manufacturing Consortium and the Forging Industry Association. All lecture presentations, exercises, videos, etc. that were used over the years in

[7] **Department of Defense**

subsequent offerings of this workshop are archived in a 5-DVD set titled *Foundations of JobshopLean for High-Mix Low-Volume Manufacturers*.

Annual conference: Since 2002, every year I would host the JobshopLean Conference at The Ohio State University. When selecting presenters, one of my priorities was to feature a few presentations by OSU students who had done course projects or LEAP internships at local companies, such as Pinnacle Data Systems Inc., Central Ohio Welding Industries and PR Machine Works Inc.

Online chat group: In 2001, I created an online chat group, JSLEAN. I actively moderated the discussions till 2012 when I left The Ohio State University. Its website is http://finance.groups.yahoo.com/group/JSLEAN/ . It is devoted to discussions on Lean in job shops and boasted a membership of about 1200 at one time.[8] If you become a member, you could access the discussion threads that are still archived and accessible to the public.

Educational study materials: In partnership with student co-authors, I wrote a book[9], a couple of study guides[10] and other educational materials that were purchased by members of the JSLEAN group. All proceeds from their sales were used to buy videos on Lean that helped to "stream the factory floor into the classroom" in my courses.

The JobshopLean Simulation: This simulation can engage a large group of students (or industry personnel) to teach them how to design and operate a hypothetical machine shop. Multiple runs of the simulation are used to demonstrate the impact of implementing different JobshopLean strategies for improving shop performance. Video recordings of two different runs of this simulation are posted at http://www.vimeo.com/5425379 and http://www.vimeo.com/5537406 . The first run is with the initial Process Layout for the machine shop and the second run is with a 2-cell Cellular Layout for the same shop.

Senior Capstone Design project: If a Senior Capstone Design project team needed a large data set with hundreds of routings to be analyzed, either I or a member of my research team would give them the PFAST outputs for that data set.[11] If the team asked for help on how to put the outputs to use in their project, we were happy to help them.

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[8] Now that I have personal experience in implementing Lean/JobshopLean, I concede that the industry practitioners were right and I was wrong in many arguments. They had actual experience in implementing Lean/JobshopLean whereas, being at the university, I had not personally led a complete Lean implementation at any company!

[9] The title of the book is *An IE Student's Study Guide for Bottleneck Scheduling using Theory Of Constraints*.

[10] The titles of these two guides are *Product-Process Matrix Analysis* **and** *Product-Routing Cluster Analysis*. Both describe standard methods for part family formation to design manufacturing cells.

[11] To this day, I continue to comply with requests from students from across the world if they need me to provide a PFAST Analysis Report for their project. The most recent one (in 2016) was from the University of Twente in The Netherlands to explore the possibility of implementing cells in a gear manufacturing facility.

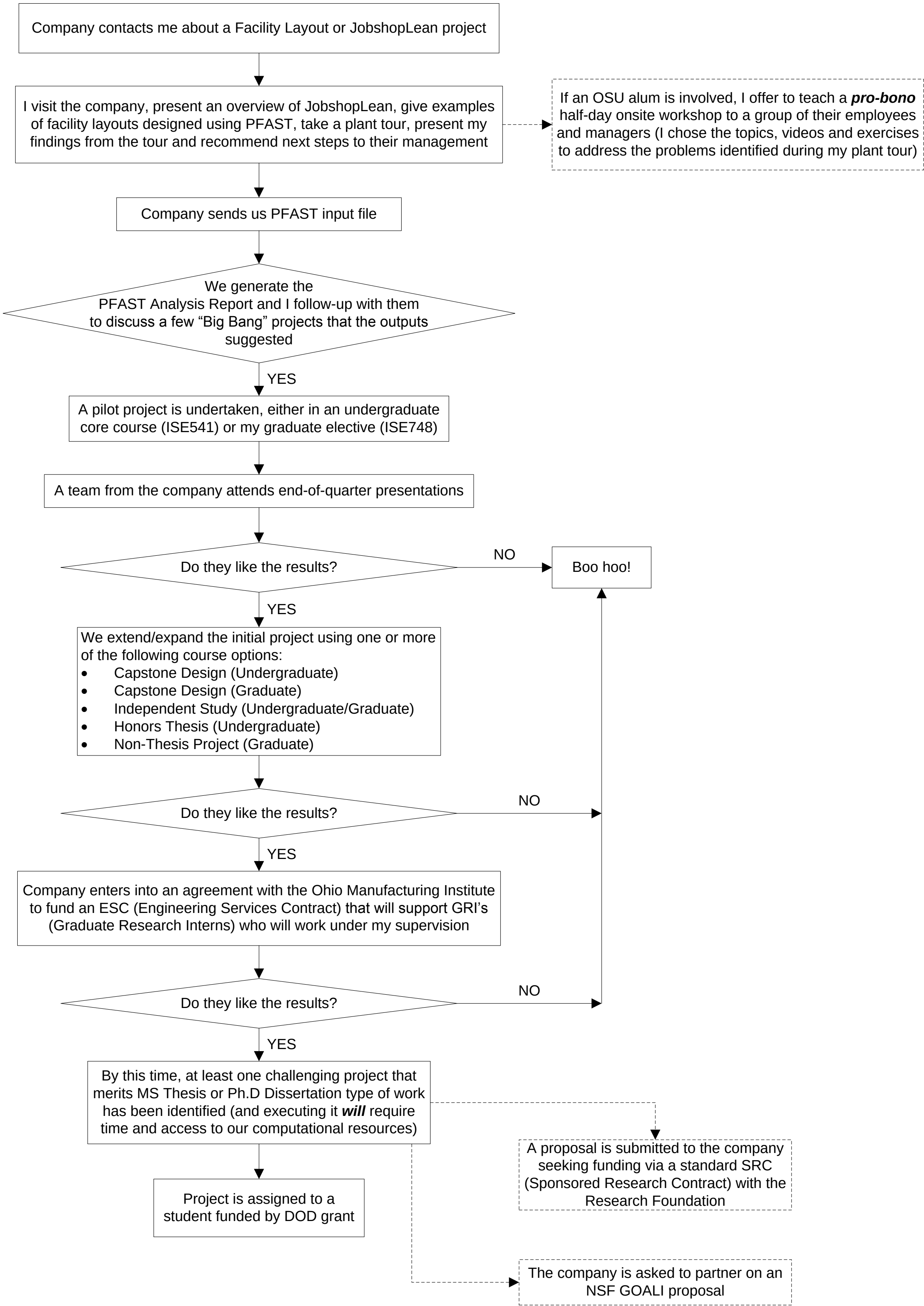

Figure 1 Process for Leveraging Co-Curricular and Extra-Curricular IE Programs

Appendix 5

Suggestions for IE Faculty Committed to Undergraduate Teaching

This Appendix may be of interest to IE faculty who are committed to undergraduate education.

Use textbooks *not* written by academics:

- Consider making these books published by the Lean Enterprise Institute (www.Lean.org) *Seeing The Whole*, *Learning To See*, *Creating Continuous Flow*, *Making Materials Flow* and *Creating Level Pull* essential reading in one or more of the core IE courses. They are written by practitioners who are intimately familiar with the Toyota Production System. They teach the IE that will surely work in industry. The Toyota Production System is universally implemented and used extensively all over the world. Yet you will find that most departments persist with a curriculum that teaches archaic and obsolete IE from the era of Mass Production. In addition, it is very easy to recognize, and therefore teach, the underlying Operations Research that would computerize the manual methods of analysis and design that the books teach.
- Perhaps you can include at least one of these other books that I used for my self-education on the TPS – Richard Schonberger (*World Class Manufacturing*), Shigeo Shingo (*Toyota Production System from an IE Viewpoint*), Taichi Ohno (*Toyota Production System*) and James Womack (*Lean Thinking*).

Work in industry for a couple of years (or at least take sabbatical leave to do so): Having a full-time job in industry is the only way to get significant work experience as an IE. I made a huge career mistake by earning my three degrees one-after-the-other without taking a job in industry. I should have worked in industry, preferably between my MS and Ph.D. degrees. What a mistake! The IE textbooks that are currently in use teach too much theory and expose the lack of industry experience of their authors. Alternatively*, and this is a poor substitute for a full-time job*, you can have a part-time presence in industry through plant tours, attending workshops, consulting, mentoring of student interns, advising Senior Capstone Design teams on their projects, belonging to online chat groups like the one hosted at www.lean.org, running a blog, etc. The best option to work in industry would be to utilize the one-year sabbatical leave that any professor is eligible for every 6 years. It is never too late to learn what you do not know!

Do not wait for the Senior Capstone Design course to teach your students to connect theory to practice: Every course in the undergraduate curriculum (even the OR courses!) is an opportunity to involve the students in real-world projects. And, once you have developed contacts in local industry, it is not too much work to find projects for other courses. Maybe you could test the engagement process suggested in Figure 1?

Take the help of your research team to make a large industry project do-able as a course project: Prior to the quarter when I had to teach the undergraduate course *Facilities Planning* or the graduate course *Design and Analysis of Manufacturing*

Systems, we would obtain a dataset from a local company and process it using our PFAST (Production Flow Analysis and Simplification Toolkit) software. Then we would analyze the outputs to whittle the dataset's size. This way, while it meant extra work for our research team, we would provide the students in either class with a manageable sample of routings (rather than swamp them with upwards of a 1000 routings).

Limit how many textbook problems you assign as homework: For a course that had an industry project, I did assign practice problems out of the textbook, but I made their submission as optional. Instead, every week the students were expected to spend time **<u>at</u>** the sponsor company to find ways to apply what was taught in class. Often, this required them to collect more data, do additional software-aided analysis, etc. every week! Okay, so this will not get you good teaching evaluations. But, do you want to be popular with your students or do what is going to benefit after they graduate and go to work as IE's?

Incorporate Lean across the curriculum: Lean is almost completely based on the IE that is practiced and taught at Toyota. Unfortunately, most IE faculty will never get to work for Toyota. Everything that they do at Toyota flies in the face of traditional IE and MBA education delivered from textbooks written by faculty with limited industry experience! In fact, when I got to teach ***two*** core courses (*Facilities Planning* and *Production Control and Scheduling*) in the same quarter, I engaged with local companies to have ***one*** industry project common to both courses. This helped me to teach the batch of students taking both classes in the same quarter that IE's need to be systems thinkers. Why? Because a well-designed facility layout **and** a good production control and scheduling **together** achieve effective shop floor control!

Here is what happened in the case of Ometek Inc., a fabrication jobshop located in Reynoldsburg, OH. The department helped this one company for an entire year! After their management team had listened to the students' presentations for the *Facilities Planning* course, they contacted me and asked, "So how can we take this excellent work by your students further?" I did that by assigning the same industry project in my graduate course *Design and Analysis of Manufacturing Systems* where more in-depth analysis was involved. At the end of this course, Ometek's management team got another battery of recommendations! Next, I put their management in touch with colleagues who were seeking projects for the Senior Capstone Design course that spanned two quarters. Finally, since the graduate course *Design and Analysis of Manufacturing Systems* was taught in the Spring quarter, Ometek decided to hire one of the students from that class as a summer intern.

Allow part of the grade for the industry project in a course to be determined by the company that sponsored the project: At the end of the quarter, I would request the sponsor company to send a representative (or a team) to listen to and co-grade all team presentations with me. *This ensured that the students visited their sponsor company at least once every week.*