2005-220

Physical Simulations in Classroom as a Pedagogical Tool for Enhancing Manufacturing Instruction in Engineering Technology Programs

Alok K. Verma, Han P. Bao
Anand Ghadmode, Swanand Dhayagude
Old Dominion University

Abstract

Lean is a powerful philosophy that advocates minimization of waste within an organization. The adoption of Lean Manufacturing philosophy by major manufacturers has created a demand for qualified personnel in this area. Higher education is not far behind in incorporating this philosophy into their curriculum. A number of universities have started offering both graduate and undergraduate courses in Lean Manufacturing. Physical simulations are often an integral part of these courses. Simulation based Lean enterprise concepts have been introduced in an undergraduate course in mechanical engineering technology program at Old Dominion University. Results show increased student participation and better understanding of Lean concepts.

This paper examines the use of simulations as a pedagogical tool and studies their impact on student learning in an undergraduate engineering technology course. The paper also discusses the assessment process to measure the impact of simulation-based instruction. An attitudinal survey has also been developed to assess the impact of the training program on student's thinking.

I. Introduction

The adoption of Lean Manufacturing philosophy by manufacturers worldwide has created a demand for workers who are trained in the Lean principles and have an eye for the waste in the value stream [1]. A previously developed Lean enterprise training program has been combined with a ship repair simulation activity to teach students about Lean philosophy and its implementation. This curriculum is part of an upper-division elective in the Mechanical Engineering technology program at Old Dominion University (ODU).

A training program in Lean enterprise was developed by the author for Northrop Grumman Newport News Apprentice School. This training program contains seven modules, which can be either used independently or as one cohesive unit. Upon completion of this course, the students will understand the fundamental principles of Lean and the value of reducing waste within an organization. They will be familiar with various techniques for implementing Lean on the shop floor including value stream mapping, 5S, cellular manufacturing, interdisciplinary teams, perfect quality and pull scheduling. First module of this training program has been incorporated into a course titled "Computer Integrated Manufacturing" (MET-445) in the Mechanical Engineering Technology Program at ODU.

A number of organizations have failed in the implementation of Lean Manufacturing by failing to sustain it [2], [3] & [8]. This is primarily due to lack of sufficient number of trained employees to reach a critical mass for organizational transformation. Training all employees in the principles of Lean is a critical part of Lean implementation process. Educational institutions can do their part by incorporating Lean within their curriculum. Changes in the CIM course are designed for two reasons. One to update the curriculum and second to produce graduates who are familiar with this important philosophy.

II. What is LEAN?

The term Lean was first coined about 15 years ago at Massachusetts Institute of Technology and later published in a book called *Machine That Changed the World,* written by James Womack and his colleagues [4]. The generally accepted definition of Lean in the industrial community is that it is:

"A systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection."

The Lean principles have evolved from the works of Henry Ford and subsequent development of Toyota Production System in Japan. Lean Manufacturing principles improve productivity by eliminating waste from the product's value stream and by making the product flow through the value stream without interruptions [1], [4] & [5]. This system in essence shifts the focus from individual machines and their utilization to the flow of the product through processes [7].

In their book *Lean Thinking*, James Womack and Dan Jones [1] outline five steps for implementing Lean:

1. Specify the *value* desired by the customer.
2. Identify the *value stream* for each product and challenge all waste.
3. Make the product *flow* through the value creating steps.
4. Introduce *pull* between all steps where continuous flow is possible.
5. Manage toward *perfection* by continuously improving the process.

Lean principles were originally applied to manufacturing only but, people quickly discovered their potential in improving other business functions within an organization like finance, human resource and contracting etc. When Lean principles are applied not just to manufacturing but to all business operations both within the organization and across all supply chains, a Lean enterprise is created.

III. Physical Simulation as a Teaching Tool

Physical simulations have a proven record as a teaching tool. Concepts often hard to grasp are made easy by the use of simulation exercises. During the simulation exercises, students take on role-playing within a manufacturing organization. Effect of various Lean tools on the productivity of the organization is studied and documented through measurement of performance metrics. These performance metrics include, work in progress, cycle time, profit/loss, production volume etc. During the current training program, simulation is performed in three phases; each thirty minutes long.

Educators have been designing, using, evaluating and writing about simulations for more than 45 years. However there are no generally accepted definitions of an education simulation or its many variations. Education simulations are sequential decision-making classroom events in which students fulfill assigned roles to manage discipline-specific tasks within an environment that models reality according to guidelines provided by the instructor. Education simulations typically place students in true-to-life roles, and although the simulation activities are "real world," modifications occur for learning purposes. [11]

Simulations weave substance-specific information into real life problems in meaningful ways that students can understand. During simulations, students typically acquire broad discipline-specific knowledge that they are able to later transfer into a professional setting. Simulations also teach much more, including the process involved in the discipline, the organization involved, and the interactions with other discipline, people, and organizations.

The entire structure of simulation is built around the concept of students participating in variety of roles within an environment, designed around the learning objectives of the course. During simulation, learning happens because the students are active and not passive in the process. They are able to experiment with various options and interact with fellow students. Increasing student's knowledge is an important goal of all education. Simulations are particularly adept at helping students acquire usable knowledge that is knowledge that can be transferred and applied to other situations. Simulations encourage purposeful use of knowledge to achieve clearly defined goals.

Another important use of simulations in education is to facilitate efforts at what has become known as "bridging the gap" between academics of profession and practice of that profession. Simulations are ideal for connecting factual knowledge, principles, and skills to their application within a profession. Simulations help students with an opportunity for decision making, and for evaluating the consequences of their decisions that no textbook or laboratory can. [12]

IV. Incorporating Lean Training in Senior Electives

The training program and simulation activity has been tested in the Computer Integrated Manufacturing course (MET-445) this year. The goal of this course is to provide the student with competency-based, hands-on learning that supports a systems approach about Lean philosophy and its implementation. Prerequisites for the course include general knowledge about manufacturing systems and sophomore level course in materials processes and manufacturing. Student responses have been collected and evaluated. Student and Instructor comments have been utilized to modify the presentations. Student comments indicated positive response towards the program content and method of presentation. The comments showed a positive attitude towards Lean and the possibility of implementing Lean in various areas at their place of work.

V. Attitudinal Survey to Assess Impact of Lean Training

The challenge of Lean implementation is in changing how people feel about their day-to-day manufacturing job. Application of Lean tools is relatively simple compared to changing the work culture and attitudes. Thus, it is important to assess the change in the attitude of people.

An attitudinal survey was created to assess the impact of Lean training on the thinking of students. The attitudinal survey assesses how a student's thinking about Lean Manufacturing has changed during the training. A score is generated from the survey from pre and post testing. The difference in the score represents the change in the attitude of students. Thus, a larger difference represents higher impact of training program on student's thinking. A copy of the survey is attached in the Appendix.

VI. Delivery Method

The course is instructor-led classroom training combined with in-class simulation exercises designed to invite class participation. This approach aids in the individualized instruction given to the participant. Instructional methods include facilitated discussion, hands-on simulation of production, and on-the-job practical applications. PowerPoint presentations are used to deliver the course, supplemented by a series of videotapes from Society of Manufacturing Engineers and Productivity Inc. Students are encouraged to participate in the Lean implementation projects. In addition a semester project on production simulation using ProModel software is also required.

VII. Ship Repair Simulation Exercise

This simulation exercise incorporates repair of two ships of different sizes. One of the ships is shown in Figure 1. During the simulation, students track performance metrics like lead-time, cycle time, rework and distance traveled by material handler while implementing various tools of Lean in three phases. This exercise takes into account logistical issues such as inspection reports, master repair schedules, emergent repairs, in addition to planned repair activities. This simulation exercise simulates repair activities such as painting, blasting, engine overhaul, shaft straightening, pipe replacement, and deck plate replacements.

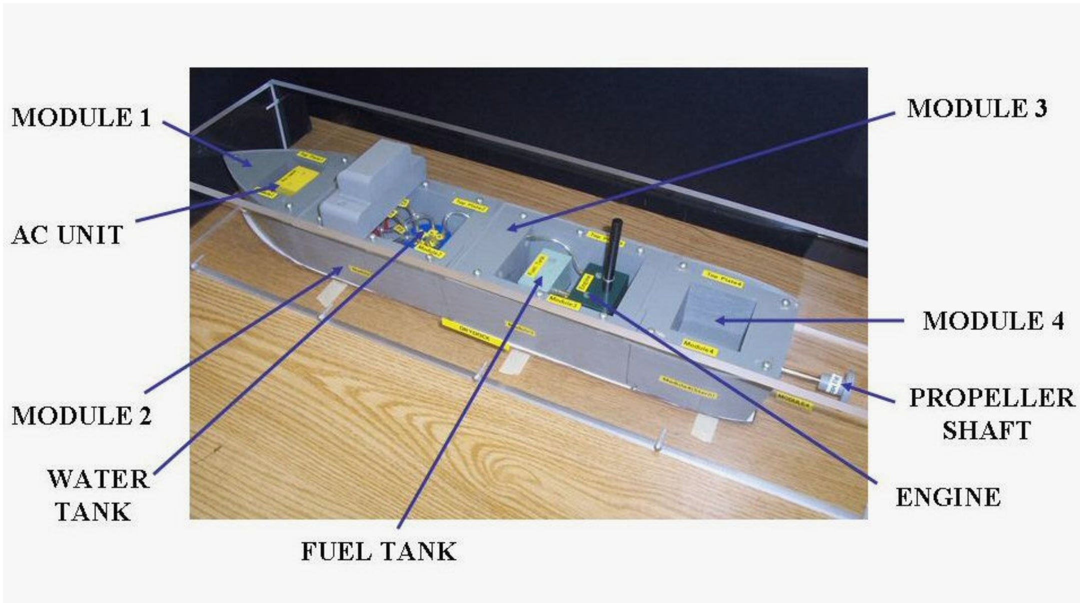

Figure-1, Ship Repair Simulation Model

Fourteen to twenty people can participate in this simulation. During simulation participants are assigned to seven different departments: planning, hull, machinery, production shop, warehouse, waterfront services, and inspection. Typical room layout is shown in Figure 2.

Figure-2, Room Layout

The simulation exercise starts with the traditional manufacturing model involving push system and functional layout. During this phase, lack of communication between different departments increases process lead-time. During the second phase, Lean concepts like 5-S, standardized work, point of use storage, and communication are incorporated. Finally, during the third phase concepts like cradle to grave approach, line balancing, and empowered teams are implemented. These three phases of simulation activity are shown in Figure 3. At the end of each phase of simulation, data such as cycle time of different repair jobs, lead-time, rework cost and distance traveled by waterfront services is collected. Using this data, impact of Lean implementation is assessed. [14]

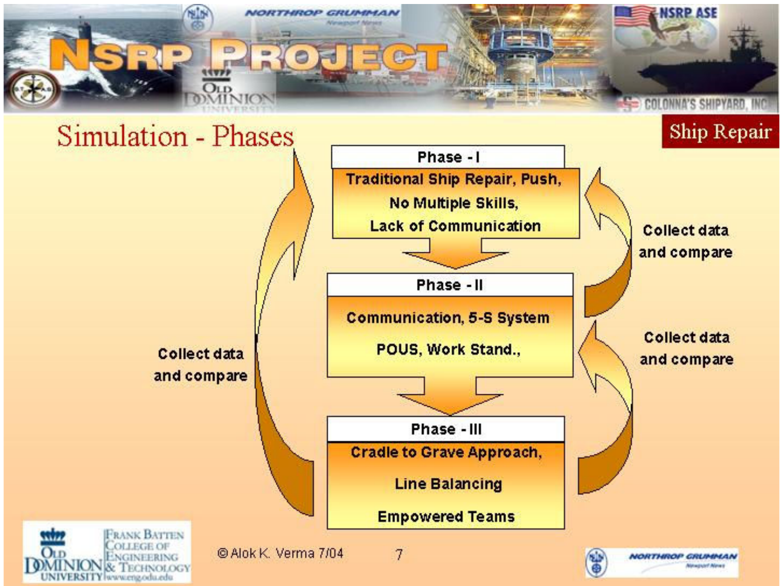

Figure-3, Simulation Phases

VIII. The Physical Model

The physical models of ships were fabricated at NGNN pattern shop. The components are fabricated from wood and include ship parts such as engine, A.C. unit, water tank, fuel tank, heat exchanger, smoke stack, propeller, propeller shaft, captain's cabin and crew cabin. The dry dock and deck plates are fabricated from acrylic. The components are assembled together using dowel pins for positioning and fastened with brass screws. The components are designed to withstand repeated assembly and disassembly. Some of these components are shown in Figure 1.

IX. Implementation of the Simulation Activity

As mentioned above, the Lean modules were implemented in a course titled Computer Integrated Manufacturing (MET-445). After being introduced to theoretical knowledge about Lean Manufacturing, the students are asked to simulate the process of ship repair. The simulation begins with the class playing the roles within a fictitious company named ABC Inc. Job responsibilities are discussed and student volunteers are assigned to various positions needed to manufacture the product. The goal for the company is to finish the repair job on time (within 13 minutes). Results of one of the simulation are shown in spreadsheet below. [13]

Task	Phase - 1	Phase - 2	Phase - 3
Start Time for Replacement of Deckplate # 1 of ship 1	**0.11**	**1**	**0.44**
Finish Time for Replacement of Deckplate # 1 of ship 1	**18.46**	**3.33**	**4.34**
Start Time for Replacement of Deckplate # 3 of ship 1	**1.5**	**0.4**	**0.2**
Finish Time for Replacement of Deckplate # 3 of ship 1	**19**	**12.12**	**6.36**
Start Time for Replacement of Deckplate # 1 of ship 2	**4.26**	**4.05**	**4.15**
Finish Time for Replacement of Deckplate # 1 of ship 2	**17.3**	**8.3**	**7.58**
Start Time for Engine Overhaul	**4.2**	**1.58**	**0.3**
Finish Time for Engine Overhaul	**16.55**	**9.07**	**6.11**
Start Time for Painting and Blasting	**8**	**8**	**7.14**
Finish Time for Painting and Blasting	**15.06**	**14.44**	**11.09**
Start Time for Shaft Straightening	**8.35**	**9.4**	**8**
Finish Time for Shaft Straightening	**9.55**	**10.22**	**8.53**
Start Time for cutting Plate # 1 of ship - 1	**5**	**0.19**	**3**
Finish Time for cutting Plate # 1 of ship - 1	**10.41**	**1.5**	**5.46**
Start Time for cutting Plate # 3 of ship - 1	**4.28**	**2.25**	**0**
Finish Time for cutting Plate # 3 of ship - 1	**10.41**	**3.56**	**1.45**
Start Time for cutting Plate # 1 of ship - 2	**5.51**	**4.45**	**5.01**
Finish Time for cutting Plate # 1 of ship - 2	**10.5**	**6.3**	**6.47**
Number of Modules on which repainting was done	**2**	**0**	**0**
Painting Cost for one module - Dollars	**50**	**50**	**50**
Lead Time - Minutes	**22.26**	**14.59**	**11.38**
Cycle Time for Replacement of Deckplate # 1 of ship - 1	**18.35**	**2.33**	**3.9**
Cycle Time for Replacement of Deckplate # 3 of ship - 1	**17.5**	**11.72**	**6.16**
Cycle Time for Replacement of Deckplate # 1 of ship - 2	**13.04**	**4.25**	**3.43**
Cycle Time for Engine Overhaul	**12.35**	**7.49**	**5.81**
Cycle Time for Painting and Blasting	**7.06**	**6.44**	**3.95**
Cycle Time for Shaft Straightening	**1.2**	**0.82**	**0.53**
Cycle Time for cutting Plate # 1 of Ship - 1	**5.41**	**1.31**	**2.46**
Cycle Time for cutting Plate # 3 of Ship - 1	**6.13**	**1.31**	**1.45**
Cycle Time for cutting Plate # 1 of Ship - 2	**4.99**	**1.85**	**1.46**
Total Distance Traveled by Waterfront Services - Feet	**22**	**14**	**14**
Repainting Cost	**100**	**0**	**0**

Table-1, Performance Metrics Spreadsheet

ABC Inc. is a general purpose marine repair company that performs work like blasting, painting, hull repair and engine overhaul. During the first phase of simulation, traditional repair and maintenance techniques are used. The employees are given strict rules to follow with very limited authority. Data is collected after the first ship repair order is complete. Average cycle time, number of employees, number of workstations, lead-time, distance traveled, and rework cost are the performance metrics that are analyzed. The numbers are input into an Excel spreadsheet. In most cases phase-1 takes 30 minutes to finish the repair job.

It is at this point that the students are reminded of some of the Lean concept taught earlier in the class. They begin to use several Lean building blocks to improve the process. Ideas such as point of use storage, 5S, multi-functional workers, and standardization surface quickly in group discussion. Systematically, the students begin to implement Lean ideas, and thus improving the process and finishing the repair job in less time. The second phase is completed and data is collected. This phase usually takes 20 minutes to complete the repair job. The students are usually excited to see the turnaround that they are responsible for; however they are reminded that the company cannot survive by simply having each shift break even. Figure 4 shows the simulation activity at the Dry Dock and at the Production Shop.

Figure-4, Simulation Activity at Dry dock and Production Shop

As the students return to the table to brainstorm ideas of how they might improve the process even greater, a new set of Lean tools is introduced in the classroom. The students then set-up and run the process a third time implementing as many of the Lean concepts as possible. The data after one shift is collected and the bottom line is computed. Typically, repair job is completed on time. At this point the students are quite excited and are very proud of their accomplishments.

X. Results

The Lean training and simulation activity has been well received by students. Comments on end of course surveys reveal that student enjoy learning the Lean concepts with the simulation exercise. Figure 5 shows the histogram of student responses from the pre and post training evaluations. The student responses were fitted to a polynomial and the value of mean is indicated by a dashed line. Figure clearly indicates that the post training response curve is skewed to the right. Before the simulation training, mean of student responses was 3.31 and after the simulation activity this mean moved up to 3.73. This indicates that the class room training utilizing physical simulations had an impact on the learning and retention of the participants.

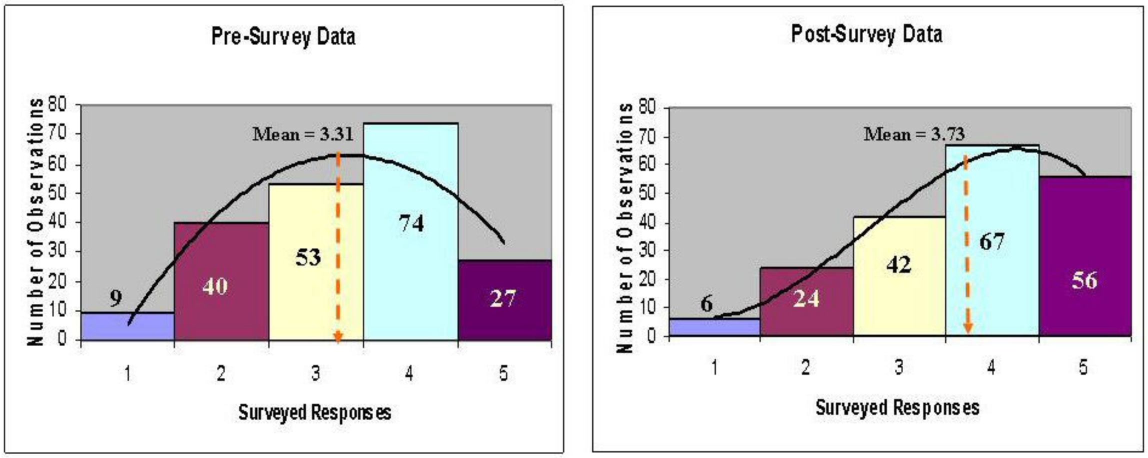

Figure-5, Plot of Student Responses

XI. Conclusions

One of the objectives of this course is to train students in the principles of Lean Manufacturing and its implementation. This study shows that, these objectives are met by incorporating physical simulations within the course material. Student learning is also enhanced by including examples of actual Lean implementation in various industries. Hands-on simulation exercises provide understanding of the concepts and first hand verification of the advantages of Lean.

Incorporation of Lean principles and ship repair simulation into a senior elective creates a course that is both engaging and educational for students. The primary goal for making this change is to ensure that students are familiar with this powerful philosophy before stepping out into real world. Comparison between pre and post attitudinal survey results indicate statistically significant improvement in students understanding of Lean concepts and tools.

Appendix A – Attitudinal Survey for Training Assessment

LEAN ENTERPRISE ATTITUDINAL SURVEY

This survey is designed to assess your knowledge and attitude towards lean philosophy. Please mark the circle based upon the following scale.

1- Strongly Agree **2**- Agree **3**- Neutral **4**- Disagree **5**- Strongly Disagree

1.	Lean Manufacturing techniques only work in large, high volume, repetitive manufacturing companies?	O1 O2 O3 O4 O5
2.	Larger production always means larger profit.	O1 O2 O3 O4 O5
3.	Lean is only applicable to manufacturing operations	O1 O2 O3 O4 O5
4.	If we focus more on internal efficiency, it will lead to less customer attention and hence less customer satisfaction	O1 O2 O3 O4 O5
5.	People should always be told what to do.	O1 O2 O3 O4 O5
6.	It's always better to have high Inventory level which acts as a cushioning when demand increases.	O1 O2 O3 O4 O5
7.	Workers should be cross-trained to be able to perform every task in production cell.	O1 O2 O3 O4 O5
8.	Overproduction is a waste?	O1 O2 O3 O4 O5
9.	Batch size should be increased to increase productivity	O1 O2 O3 O4 O5
10.	Its better to produce more than required countering reduction in volume due to defects	O1 O2 O3 O4 O5
11.	If we reduce waste, workers will sit idle	O1 O2 O3 O4 O5
12.	Quality level is independent of inventory.	O1 O2 O3 O4 O5
13.	JIT means zero inventories.	O1 O2 O3 O4 O5
14.	If a factory maintains inventory, it is not lean	O1 O2 O3 O4 O5
15.	Implementing scheduled maintenance increases downtime for equipment, does it increase productivity?	O1 O2 O3 O4 O5
16.	Adding new machinery in the production line will make the existing process faster and efficient.	O1 O2 O3 O4 O5
17.	Production line should be stopped as soon as a defect is found	O1 O2 O3 O4 O5

Acknowledgements

The authors are grateful to National Shipbuilding Research Program for funding the research project for the development of ship repair simulation tool and associated training program.

Bibliography

1. Lean Thinking by Jim Womack, Simon & Schuster, January, 1996.
2. Transitioning to Lean Enterprise: A Guide for Leaders – Volume-I, Executive Review, Massachusetts Institute of Technology, 2000.
3. Becoming Lean by Jeffrey Liker, Productivity Press, February, 1998.
4. The Machine That Changed the World by Jim Womack and Daniel T. Jones, Harper Perennial, New York, NY, 1991.
5. World Class Manufacturing: The Next Decade by Richard Schonberger , Free Press, May, 1986.
6. Lean Manufacturing for the Small Shop by Gary Conner, Society of Manufacturing Engineers, 2001
7. Lean Manufacturing a Plant Floor Guide Edited by Allen, Robinson & Stewart, Society of Manufacturing Engineers, 2001
8. Lean Manufacturing, Tools, Techniques, and How to Use Them by William Feld, The St. Lucie Press, 2001
9. Proceedings of the International Lean Manufacturing Conference, Lexington, KY, May 2002.
10. Proceedings of the Lean Shipbuilding & Ship Repair Forum, Lexington, KY, June 2002. Proceedings of the 2002 Gulf Coast Lean Manufacturing Conference, Gulfport, MS, Feb. 2002.
11. Using Simulations to Promote Learning in Higher Education by John P. Hertel and Barbara J. Millis, Stylus Publishing, LLC, 2002
12. Simulation in the Classroom by John Taylor and Rex Walford, Penguin Education, 1972
13. Lean Enterprise Simulation Project Final Report Submitted to NSRP-ASE Program by Alok K Verma, 2004
14. Lean Simulation Exercise for Ship Repair Industry –Thesis Report by Anand Ghadmode 2004

Biography

ALOK K. VERMA

Alok K. Verma is Associate Professor and Director of the Automated Manufacturing Laboratory at Old Dominion University. He also serves as the Chief Technologist of the Lean Institute at ODU He received his B.S. in Aeronautical Engineering, MS in Engineering Mechanics and PhD in Mechanical Engineering. He joined the Mechanical Engineering Technology Department at ODU in 1981. He is a licensed professional engineer in the state of Virginia, a certified manufacturing engineer and has certification in Lean Manufacturing. His publications are in the areas of Fluid Dynamics, Advanced Manufacturing Processes, CAD/CAM, and Robotics. Dr. Verma has developed the training program in Lean Enterprise & Design for Manufacturing for Northrop Grumman Newport News and continues his participation through a joint National Shipbuilding Research Program (NSRP) project to develop and design new simulation tools for Lean Enterprise training. He has delivered keynote address at several international conferences on Lean Manufacturing and offered Lean training for companies in Hampton Roads area. Alok Verma has co-edited the proceedings of the International Conference on CAD/CAM & Robotics for which he was the general chairman. He is active in ASME, ASEE and SME.

HAN P. BAO

Han P. Bao is a Professor in the Department of Mechanical Engineering at Old Dominion University. He also holds the Mitsubishi Chair of Manufacturing Engineering at ODU. He has taught a wide variety of courses in manufacturing, the current ones being Concurrent Engineering, Computer-Integrated Manufacturing, and Contemporary Manufacturing technology. His current research includes fuzzy multi-attribute utility function as an approach to cost estimate new products and processes, and development of a quantitative metric for capturing the development complexity of a design or manufacturing system. He has consulted with Westinghouse, IBM, Caterpillar, Texas Instruments, and other companies. He is a member of the SME, IIE, NAMRC, and ASME, and is a registered professional engineer in the State of North Carolina.

ANAND GHADMODE

Anand Ghadmode is a graduate student in the department of Mechanical Engineering at Old Dominion University. He received his B.S. in Mechanical Engineering from Shivaji University, Kolhapur in 1998.He has worked as Senior Engineer for three years in Mazagon Dock Limited, India. He has worked with Prof. Alok K. Verma in developing Lean simulation exercise.

SWANAND S. DHAYAGUDE

Swanand S. Dhayagude is a graduate student in the department of Mechanical Engineering at Old Dominion University. He received his B.S. in Mechanical Engineering from Pune University, India in 2003. He is currently working in Lean Manufacturing and Design for Manufacturing using Quality Function Deployment. He has worked with Prof. Alok K. Verma in developing Lean simulation exercises for National Shipbuilding Research Program.