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Value Methodology & Frugal Engineering: New frontiers in an engineering curriculum?

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Are ***Value Methodology*** & ***Frugal Engineering*** new frontiers in a collaborative engineering and business curriculum?

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ABSTRACT

This paper presents the development and teaching of a university level course for college seniors and graduate students on Frugal Engineering and Value Analysis. We developed and offered the course to both business and engineering students. Here, we present the need for teaching frugal engineering in an engineering curriculum. Value Methodology or Value Engineering, along with Quality Engineering, are key components of frugal engineering. "Wicked" problems and their challenges are also presented in this course, along with wicked problem-solving strategies. While the concepts behind Value Engineering were developed in the 1940s and frequently applied in industrial, manufacturing, construction, and defense projects, they are rarely taught in engineering/business colleges today.

We present a roadmap for teaching such a course. We also detail the certification process by SAVE International (formerly Society of American Value Engineers). A sample ABET based syllabus, along with a detailed class schedule is also be discussed. After completion of the course, students are eligible to take the Value Methodology Associate (VMA) exam to be certified as VMAs (Value Methodology Associates). This certification will be compared to a Lean/Six Sigma certification that is popular with students today.

BACKGROUND

Design and Analysis of process, products, and projects are core competencies of business analysts and engineers. In order to develop these competencies, most engineering curricula in mechanical and industrial engineering programs provide coursework in Computer Aided Design or Finite Element Analysis. These tools are especially useful and applicable after a design is conceptualized and the primary challenge is to develop a detailed design. In detailing stages of design thinking, the five commonly established steps [1,2] are to

1. Empathize,
2. Define,
3. Ideate,
4. Prototype, and
5. Test.

Most work and papers on these topics focus on ***what*** needs to be done at each design stage. We propose a frugal engineering framework with a well-established Value Analysis technique as a core to teaching a structured methodology on ***how*** to transform a conceptual idea into a more detailed design.

In order to prevent the overengineering of solutions that are so common in products, projects, or processes that are loaded with features that have little value to most consumers, we focused on frugality in design thinking as a way of bringing products within the reach of a larger segment of the population by focusing on the customer. Frugal Engineering can be defined as a process that reduces product/process/project complexity with a focus on customer need and affordability. Some universities have already seen the need for frugality, as in the ***Frugal Innovation Hub*** at Santa Clara University (https://www.scu.edu/engineering/labs--research/labs/frugal-innovation-hub/), and the Social E Lab at Stanford University where complete projects as part of a program in Design for Extreme Affordability. (https://dschool.stanford.edu/classes/design-for-extreme-affordability). The coursework offered by these pioneering schools focus on the design thinking steps presented above.

Our approach to frugality and frugal design is to utilize Value Analysis Methodology, a technique developed by Lawrence Miles during World War II, when shortages of parts was common, as a way to teach Frugal Engineering to engineering and business students. Value Analysis is a systematic and structured methodology that focuses on 'function' and 'customer need'. The goal of frugal engineering is to transform new projects, or existing products and processes into functional but more affordable versions for users. Consequently, frugally engineered products are more applicable and accessible to a larger segment of the population. In our opinion frugal engineering and value analysis are essential to studying design on a global scale

WICKED PROBLEMS

In teaching design strategy and tools, we found it was important for students to learn about "wicked" problems because solution strategies to this class of problems is analogous to a design challenge with multiple, competing, and realistic constraints. According to John Camillus [3], " a wicked problem has in-numerable causes, is tough to describe, and doesn't have a right answer…. they're the opposite of hard but ordinary problems, which people can solve in a finite time period by applying standard techniques."

These are typically problems that have multiple stakeholders with each having a different definition of the problem. Each wicked problem is unique and there is no stopping point in establishing an optimal solution – much like a design problem. As a result, wicked problems cannot be solved; instead they have to be managed or engineered for the *best* possible result or outcome. Many challenges in real life are wicked problems and Camillus [4] presents a "Business of Humanity" framework for addressing some of these. Wicked problems include challenges in addressing ESG as part of corporate governance or an engineering strategy for an organizational approach to sustainability.

VALUE ANALYSIS

SAVE International (formerly the Society for American Value Engineers), (https://www.value-eng.org/) is the professional society that certifies professionals who practice Value Analysis. The SAVE International website describes "Value Methodology (VM) as a systematic and structured approach for improving projects, products, processes, services and organizations. VM, which is also known as Value Engineering, is used to analyze and improve manufacturing products and processes, design and construction projects, business and administrative processes, and both public and private sector services and organizations."

In a value engineering analysis, “VM strives to achieve an optimum balance between function, performance, quality, safety and cost.”, thus resulting in maximizing value to the customer [5].

While ‘Value’ is in the eyes of the beholder, it is broadly defined as

$$\text{Value} = \text{Function} / \text{Cost}$$

A Value Analysis or VM study follows a structured eight step path [6]:

1. Preparation: Here, the VM study scope and duration is established. Project goals and objective and budgets are identified. Key stakeholders and VM team members are also confirmed. Project logistics and level of effort of team members is established.
2. Information: Information is gathered to better understand the project. The current state of the product, process, or project is reviewed. Stakeholder perspectives are explored and gathered information must be questioned and analyzed.
3. Function Analysis: This section is complex, but core to the methodology of Value Analysis. The project is analyzed to understand and clarify the required functions. In order to do so, functions must be identified, classified, and organized. Then, resources are allocated to functions and functions are prioritized for value improvement.
4. Creativity: Generate ideas on all the possible ways to accomplish the required functions. All ideas associated with each function are recorded for further review. Brainstorming techniques are utilized at this stage.
5. Evaluation: The large number of ideas generated in the previous stage are synthesized. Those have promise are selected for development into specific value improvements. Each feasible idea/improvement is discussed with the team.
6. Development: Here, ‘best’ alternative(s) for improving value are selected and developed into a series of proposals and recommendations. Each feasible idea or alternative is put into a framework that will allow decision makers to make choices.
7. Presentation: Present the value recommendation and best alternatives to the project stakeholders. This includes a final report and presentation.
8. Implementation: This is of course, a critical part of the VM study, but one that was not completed by the class. Here, the VM team hands off the project to the sponsor. The sponsor establishes an implementation team that may or may not include VM team members. Ideally, the implementation progress is routinely tracked or audited.

Value Analysis is inherently multi-disciplinary consisting of both domain experts and trained value methodology professionals.

COURSE DEVELOPMENT

The authors developed and taught a 3-credit course in Fall 2022 at the University of Pittsburgh titled “Frugal Engineering & Value Analysis” for both engineering and business students. The course was dual numbered for business and engineering and also open to graduate students in both areas. Despite being a new course, it drew 24 students (12 undergraduate and 12 graduate), majoring in a broad range

of disciplines including industrial engineering, bio-engineering, chemical engineering, supply chain management, and information systems. Three students majored in business while 21 students studied engineering. Teaching the course validated our premise that VM is an integrative method, closely aligned to industrial engineering that has the potential to analyze systems including processes, products, and projects. The method also brings together a broad range of management and engineering tools to focus on customer needs and functionality.

Course Objectives

This course focused on the principles of frugal design of products and processes. Foundational skills in Value Engineering/Analysis including tools such as Functional Analysis, RACI matrices, Pareto Cost models, etc., were detailed. Additionally, topics such as Customer Needs Identification, Quality Engineering, Operational Excellence and Lean Process Engineering were integrated into developing frugal product and process designs. After completing the course, students are eligible to take the exam offered by SAVE International to be certified as a Value Methodology Associates (VMA).

Learning Outcomes

This course is expected to provide students with exposure to the spectrum of ABET defined outcomes:

a. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors,
b. an ability to communicate effectively with a range of audiences,
c. an ability to recognize professional responsibilities in engineering situations and make informed judgments, which consider the impact of engineering solutions in global, economic, and societal contexts,
d. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives,
e. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions, and
f. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Note that all ABET student outcomes except 3.1 (https://www.abet.org/wp-content/uploads/2023/01/23-24-EAC-Criteria_FINAL.pdf) can be assessed in the course. However, this assessment was not done since this is not a core class that all students must take.

Course Schedule

Lectures were held once each week in a 3 hour session. This worked particularly well. There was one occasion where 2 classes were held back-to-back in order to support a guest speaker's schedule.
The focus of each class is shown below:

- Introduction & Overview: Class Logistics
- Frugal Engineering
- SAVE International, The Concept of Value
- The rationale for Frugal Engineering: the Business of Humanity

- Wicked Problems as a Strategy for Design
- Value Engineering (VE) Job Plan: A Systematic Approach
- Function Analysis
- FAST diagramming
- Conducting a VM Study: Creativity and Evaluation Phase
- Conducting a VE Study: Development Phase
- Conducting a VE Study: Presentation & Implementation
- Quality Engineering & Management

Projects

Two group projects were required in class. The first project was a common project (re-engineer a digital alarm clock), and the second project was customized for each group. Projects ranged from existing products that were re-engineered using VM methodology to service processes that were value engineered. Topics included:

- Material Handling System Improvement at the Pittsburgh Siemens Energy Service Center
- Frugally Engineering the "Organ Transplant Process" at UPMC.
- Frugally Engineering the patient appointment process at the Pitt Dental School
- Function Analysis for a "Smokeless Cook Stove," .

We organized students into different groups for each project. This allowed them to work with multiple team members. Each project team was expected to make a presentation of 15 minutes for each project. Every group member was expected to be actively involved in the oral presentation. Reports were collected after the last presentation was completed. Presentations were graded on a rubric that emphasized clarity, content, and smoothness.

Grading

Grading was equally divided between the two projects and exams. Six quizzes were provided in class but these were not graded and students used them as practice for the final exam. Students were given a choice of exams for the final – they could either take the VMA certification exam administered by SAVE International that would allow them to be certified as a Value Methodology Associate or they could take a class based traditional multiple-choice final exam. The certification exam is a computer based, online proctored exam consisting of 60 multiple choice questions with a passing score of 60% at a cost of $180.

Results

Considering this was taught as a pilot course, jointly taught by two instructors (one each from engineering and business), the course received good evaluations; 75% of students responded to the course survey (18/24), equally divided among graduate and undergraduate students. Graduate students rated the course higher overall (4.55/5.00) than undergraduate students (3.83/5.00). Some of this discrepancy is because undergraduate students did not feel that the assignments contributed to their understanding of the subject matter (3.11/5.00) versus graduate students who were much more satisfied with the assignments (4.55/5.00).

A summary of undergraduate comments on course content is shown below:

- Very interesting course. Real and applicable material. excellent variety of speakers with combined centuries of experience, great experience and a lot of value.
- Put a large emphasis on learning the material for the VMA exam and doing practice exams in class.
- In class examples very helpful
- The examples of frugal engineering throughout the world and the concepts of the fortune at the bottom of the pyramid helped me understand the overall importance of this subject.
- I think that the practice quizzes and midterms were helpful preparation for the certification exam
- I love the idea of frugal engineering, and the beginning weeks of the class was fantastic. I loved learning about jugaad and the different aspects of frugal engineering..

The summary of graduate student comments (below) is similar:

- Course provided many real-life examples.
- The guest speakers were able to explain material in a different fashion with good examples.
- This will be useful for us to apply in industry.

Our focus on the course was more on learning and less on the grades. We emphasized that everyone in class starts with an A grade. This was especially appreciated by students. However, as the focus turned towards passing the VMA certification exam, students felt more pressure. As noted, students were given a choice of taking a final exam or completing the VMA certification exam in lieu of the final.

Thirteen students (out of 24) chose to take the online VMA certification exam. More than 50% received VM certification. Of note was that 5 of the 6 students who failed the exam were not native speakers of English. All those who passed were native speakers. 3 of the 6 students who failed the exams missed the passing grade by 1 question. If they failed the exam, what grade did they get for the course? If they took the VM, does this imply grade is based on midterm only?

Value Methodology (VE), Lean Six Sigma (LSS), Total Quality Management (TQM), and the Theory of Constraints (TOC) : How does VM fit in and how they can work together.

LSS combines the TQM tools with TOC concepts. The authors believe that LSS and VE can be combined to achieve the goal of maximizing customer value. While the tools used in LSS and VE may look different, the synergy between these approaches is overwhelming. We provide a sample of 'similarities and differences' between VE and LSS,' which we hope can provide valuable ideas and insights that augment the benefits of using the approaches concurrently, instead of using the capability of just one approach.

LSS uses a 5-step approach often referred to as the DMAIC (Define, Measure, Analyze, Improve, and Control) method [7]. VE utilizes an 8-step approach described earlier in the paper. In utilizing the LSS approach to process improvement, the following TOC concepts [8] are utilized:

- A system is as strong as its weakest link.
- Things do not average out in a "coupled" system where statistical fluctuations exist.

In the section below, we reproduce and paraphrase a summary from the paper, **Value Engineering Synergies with Lean Six Sigma** by Mandelbaum J. et. al.[7].

- LSS was developed as a business process and quality improvement initiative in manufacturing. VE originated in the industrial community during World War II when many manufacturers were forced to substitute materials and designs as a result of critical material shortages.
- VE explicitly considers cost by collecting cost data and using cost models to make estimates for all functions over the life cycle. In VE, some waste can be tolerated if it is necessary to achieve a function that reduces the life-cycle cost. Safety stock to mitigate occasional supply disruption is a good example.
- The focus of LSS is by eliminating waste reducing process variability through the use of statistical tools on process performance data. LSS identifies root causes of problems or variations.
- The focus of VE is customer focused function analysis. In determining improvements, VE's function analysis identifies areas that cost more than they are worth. VE's separation of function from implementation forces engineers to understand and deliver the requirements.
- In reviewing required functions that cost more than they are worth, VE uses structured brainstorming to determine alternative ways of performing them. LSS brainstorms to identify how to fix the root causes. Because functional thinking is not the common way of examining products or processes, VE augments the structured innovation process in a way that generates a large number of ideas. Enormous improvements are possible by determining which functions are really required and then determining how to best achieve them.
- VE develops solutions by evaluating the feasibility and effectiveness of the alternatives. LSS emphasizes solutions that eliminate waste and variation and sustain the achieved gains. VE eliminates waste in a different way. VE separates the costs required for basic function performance from those incurred for secondary functions to eliminate as many non-value-added secondary functions as possible, improve the value of the remaining ones, and still meet the customer requirements.
- An LSS focus on quick wins may preclude an in-depth analysis of the situation. Without analysis, projects can sub optimize or even work in opposition to one another. Using function analysis should prevent this sub optimization. Developing an effective design that does everything a user wants from a performance perspective and from the perspective of design considerations while not costing too much or weighing too much will almost always benefit from the group perspectives and discussions of the Function Analysis and Creative Phases of the VE job plan. VE links the customer requirements to the design to manage cost.
- The distinguishing feature of VE is the use of the Function Analysis System Technique (FAST) diagram.
- LSS (Green belt and black belt) certification is non-standard [9]. These are available from a multitude of institutions and can range from a weekend training session to a series of courses for a semester or two. VMA certification is standardized, and the only certification agency is SAVE International.
- Both LSS and VE have unique attributes and perspectives for process improvement. Since certain problems may be more efficiently managed by using one or both of these perspectives, exploring the full range of solution options is crucial. We conclude that VE techniques are sometimes better equipped to lead to improvements or solutions complementary to those

identified through a DMAIC approach. VE does not take the place of LSS efforts, but it does present significant opportunities to enhance LSS-developed options. For example, the DMAIC approach is more relevant to a narrowly focused issues such as reducing rejection rates in an automated assembly line versus the VMA approach that may more relevant in redesigning or reconceptualizing a consumer product such as a can opener.

LSS is popular in current engineering and business school curricula. VE coursework at colleges and universities has largely disappeared, even though the methodology is core to customer focused process, product, and project reviews and improvements. We believe that the newly implemented course will fill the gap in engineering and business curricula. In particular, it is our hope that Frugal Engineering & Value Engineering become integral topics to a design curriculum. The frugal engineering and wicked problem framework is important to establish the environment where VE methods are the most effective. In our informal feedback with students, these lectures were much appreciated, and VE was seen as a tool to implement solutions to wicked problems and designs that reach much of the less fortunate population.

Future

This course will be offered in Fall 2023 and beyond. Based on informal student feedback, we plan to reorganize the lecture schedule. SAVE (Value Engineering) basics and content will be offered in the first part of the semester. The pedagogical framework of Frugal Engineering and Quality will round out the second half of the semester. With this, students will be able to take the SAVE exam soon after the semester midterm and be better prepared.

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