122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society

Paper ID #11236

Application of Life Cycle Analysis with Systems in an Introductory Materials Course

Dr. Craig Johnson P.E., Central Washington University

Dr. Johnson is the coordinator of the MET Program at Central Washington University. He is also the Foundry Educational Foundation Key Professor and coordinates the Cast Metals Program. This will be is second year as the Chair of the Pacific Northwest Section.

Prof. Charles Pringle, Central Washington University

Charles Pringle is a professor in the Mechanical Engineering Technology program at Central Washington University. Charles teaches upper division courses including the senior capstone course.

Application of Life Cycle Analysis to Systems in an Introductory Materials Course

Abstract:

Application of materials Life Cycle Analyses (LCA) to structures and systems addresses both course outcomes, such as ABET 9a, 3i, 3j, and our program objectives. This effort is directed at improving pedagogy in an introductory materials course to meet the above goals, and 3j (societal and global issues) specifically.

The field of LCA is quite mature and has typically been presented in introductory materials courses. A typical approach to LCA targets a product or part that features a single material. LCA is then applied to this material through its lifetime.

A new approach was created to apply LCA in our introductory course. It was observed that students needed guidance to connect a system failure, with a material failure. Here students apply safety and performance ratings to a structure or system while parsing out particular devices and corresponding materials for LCA. The structure/system becomes a framework for discussion of LCA elements.

Student performance was measured by comments and surveys, and then used to assess the effectiveness of this effort. Results showed that students did perform both LCA and rate structural system integrity. Surveys were directed at student motivation and participation.

Introduction:

Life Cycle Analysis (LCA) typically refers to the analysis of the life cycle of a material, or sometimes a product. One definition found in Wikipedia is "a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling)[1]." Another definition from the Environmental Protection Agency is quite similar, "…a 'cradle to grave' approach for assessing industrial systems[2]." But what about issues that pertaining to entire systems, and their associated failure, due to the lack of relevant scope of an LCA? Now the description widens to something like 'Life Cycle Analysis of Materials and Associated Products in Large Systems Failure Analysis.' It's a messy way of describing the visceral connection (and perhaps the singular failure mechanism) regarding material degradation and its effect on failures of large systems or structures. There appears to be real problem with terminology related to this scenario, and the importance of basic materials concepts to the viability of our civilization's infrastructure; that may not be as apparent to our citizens, much less our students.

For example, a financial research group[3] published an article last summer about the 'United Petro States of America' (tongue-in-cheek) in which they stated the U.S. is now the biggest global producer of crude oil! Some associated critical information is that the Interstate Natural Gas Association of America predicted that more than a half million miles of pipeline must be laid (to support 1.2 million new wells) by 2035. And we already have a few millions miles of pipelines in the U.S. In 2014 the Association of Oil Pipelines and American Petroleum Institute stated that, "A barrel of crude oil or petroleum product shipped by pipeline reaches its destination safely more that 99.999% of the time." But another way to look at, from the DOT's Pipeline and Hazardous Materials Safety Administration, shows that in the last couple years there has been a leak more the once a day in the nation[2]. Is this reasonable?

One of our student outcomes, ABET criterion 3j states that a student has, "a knowledge of the impact of engineering technology solutions in a societal and global context"[4]. It would seem appropriate to consider the viability of our civilization's infrastructure as a 'societal' and perhaps a 'global' issue. Regarding natural gas in the U.S., "90% of rural gathering lines are not subject to federal regulations for construction and safety"[3]. So where does a student gain an appreciation for the pivotal role materials play in the continued successful operation of pipelines? And what about other large systems such as transportation (e.g. roads, bridges) or power (e.g. transmission, generation)? It is this specific issue upon which this research is focused.

Method:

Our university offers a mechanical engineering technology program in which students gain knowledge of materials starting with an introductory course. Though the major outcome of the course is a classic 'structure property relationship', there is room to consider other outcomes such as 3j. It was decided to take the first few weeks of instruction and overlay an appropriate activity. The more specific outcome was to have students be able to critically review the application of materials in large infrastructure systems using LCA and predict failure implications with regard to various types of costs (e.g. financial, safety, efficiency).

Pedagogically, an education scenario had to be developed. To fit the summer-to-summer time frame of ASEE publication, a single effort in the fall was targeted. A time frame of up to four weeks was allocated, but with the constraint of being in addition to the normal content of the course. Since the existing course had a strong on-line presence, an asynchronous education component was possible.

The literature provided direction for activity development. Dalrymple[5], et.al, made a strong case for 'Disassemble/Analyze/Assemble' (DAA) activities. Their results indicated that DAA activities "elicited significantly higher ratings of learning, enjoyment, and perceived helpfulness than traditional instruction." Another study by Menekse[6], et.al, concentrated on 'Differentiated Overt Learning Activities' (DOLA), which resulted in "students scored higher". DOLA adds an 'interactive' and 'constructive' aspect to a framework of 'active' activities. With this advice, we created an education activity.

Four parts comprised the activity were created. The activity sequence started with asking students to define a material and a related large system; and then moved through aspects of related maintenance, regulation and costs. Examples were given and followed through all four parts, so that students would have real-time comparisons. A copy of all four LCA activities is included at the end of this paper.

The activity was applied to two sections of our introductory materials course in the fall of 2014. Documents were managed on-line and discussed in class over all time frames. Each assignment was given at the beginning of the week, discussed during the next class period, and then turned in at the next class meeting and subsequently analyzed.

Part one was titled: “Defining a Part in a Large System and its Related Critical Material”. Part 1 had four tasks (formed as questions). Task 1.1 Identify an appropriate structure or system of interest. Then (task 1.2) pick and describe an appropriate part/device/component within your structure/system. Then task 1.3 is to make sure your chosen part is ‘critical’. A rating system is used to verify that the chosen part may both degrade and cause the system to fail in an unsafe manner. Finally in task 1.4 a specific material of interest is specified. This material may comprise the whole part (e.g. a steel pipeline), or be critical to the function of the part (e.g. the lining of a brake).

Part two was titled, “Defining your Part and Material Maintenance”. The first task is to find metadata associated with your chosen part and material, such as finding the entities that maintain the part and any owners of the part. Then students are asked to describe failure scenarios constructed around their part and material. The third task is to find out how the part is made and how their material is manufactured or assembled into the critical part. Finally, a description of current maintenance and (if any) inspections is required.

Part three was titled, “Defining Aspects of the Cost of Part Maintenance/Inspection/Regulation”. First, a classic Life Cycle Analysis is done on the part and material. Then all related ‘stakeholders’ (e.g. owners, regulators) of this part/material are identified. Thirdly, students are asked to find out how the various stakeholders interact when a failure occurs (e.g. legal, fiscal). Finally, students are asked to discuss the real ‘costs’ related to the part/material/system failure.

The last part concentrates on failure prevention and is titled, “Prevention of System and Structures Failures, and Related Costs”. Students are asked to create a sustainable maintenance and inspection plan for their system or structure. Then they are asked to assign costs to their plan, and compare these costs with their previous costs related to the failure of their system or structure. Finally, they are asked to suggest an improvement to the system or structure (outside of their new maintenance plan). This is intended to generate solutions that are unconventional.

Results:

Assessment of outcome achievement was accomplished using surveys and comments. As yet there is no longitudinal information. The two sections totaled 55 students. Data was extracted from work handed in as well as separate instruments.

Student comments and a survey showed that by far students enjoyed the activities (98%) and that they found it valuable (96%). The survey only asked two questions (see Table 1). But comments were reviewed for content with regard to outcomes and other relevant issues. Data concerning the most interesting aspect of the activity showed that 45% of students referred to ‘societal issues’. Students commented on aspects of the activity they focused on where 80% targeted the system or structure itself. The ‘material’ captured 12% of their focus, with the part at 4% and ‘other’ (e.g. stakeholders, etc.) at 4%. There were other aspects of the data that were of interest. First, some students did not feel that they selected an appropriate material, part or system/structure (15%) and wanted more preparation in the beginning of the activity. A second aspect was that a sizeable minority of students focused on the material or part more than the societal effects of the system or structure (20%). Last, a minority of students desired some sort of group interaction during some portion of the activity (12%). A summary of this results are shown in Table 1 below:

Table 1: Results of Survey Data

	Percent	
From student comments: Did you enjoy this activity?	98	
From student comments: Did you find this activity valuable?	96	
From the data: Students reflecting on a poor initial topic choice:	15	
From the data: Students focused on a system or structure:	80	
From the data: Percent of students focused on a specific material:	12	
From the data: Percent of students focused on a specific part:	4	
From the data: Percent of students omitting societal effects of their system:	20	
From the data: Percent of students desiring group logistics:	12	

Students commented that the LCA activity sequence was valuable, as shown in the samples below:

> “It was cool to actually be involved in the engineering aspect of a current world problem.”
>
> “The most enlightening aspect of this project for me has been researching and understanding the life cycle of a structure or piece of equipment on not only the large scale but also on the individual systems level.”
>
> “The most interesting part of this LCA assignment was learning more about how a system works and why recent failures in the system may be unsurprising.”
>
> “The aspect of thinking of the smallest part of a machine that could fail and cause so much damage was very helpful to me.”
>
> “I liked how the activity made me look closer at something I would normally take for granted.”
>
> “As someone who’s interested in aircraft/spaceflight, researching what exactly happened to the Space Shuttle Challenger was very interesting.”
>
> “The most enlightening part of the assignment was finding the stakeholders and the costs of the failures that could occur.”
>
> “Understanding the way all the systems combine to form a complex structure gives a more in depth understanding of the life cycle of that structure.”

> "It brought my attention to how a single material can drastically affect the normal operation of a very expensive mechanical system."

Since our metric for Outcome 3j is measured in different courses, there was no longitudinal data available. Extending that metric to our introductory course is still under discussion in our program.

Discussion:

This four-part LCA activity was developed and executed in a relatively short time. Thus, there is now a benchmark structure to the activity. But there were some interesting issues that were discovered during this first deployment. The present version requires individual students to go through the series of activities with class and advisor interactions. And this was quite effective according to the feedback. But though the existing activity meets much of the DAA criteria, some of the DOLA qualities could be improved.

For example, one issue observed in the results was that some students felt that they selected an inappropriate material, part or system/structure, right at the beginning (see the above results: 15%). The LCA activity was begun the first day of class. This means that students had various backgrounds coming into the activity. A suggestion might be to delay the start of the activity for a week or two, so that a baseline of materials concepts may be developed.

Another observation from the students was that a minority of them (above, 12%) desired group interactions. Some of this was related to finding a good part/material and structure/system, while others wanted a group effort to find appropriate data for existing systems.

Suggestions for improvement include a modification of the initial activity. Perhaps a 'brainstorming' session could be facilitated with a focus on selection of appropriate part/material and structure/systems. This could also help students think through the entire LCA activity and 'decouple' or 'analyze' the relationship of the 'system' to a single point of material failure. If this brainstorming was couched in a group setting, this might help the initial selection process, as well as promote a more comfortable learning environment.

Conclusion:

An educational activity was created to support ABET outcome 3j related to engineering in social and global contexts based on DAA and DOLA. It was targeted at an introductory materials course, and implemented in two class sections. Students performed LCA and other analyses on a part/material within a large system or structure. Surveys and student comments indicate that the activity was successful. Future work includes the development of an initial group-based brainstorming session to improve the LCA system selection process.

References:

1. Wikipedia, http://en.wikipedia.org/wiki/Life-cycle_assessment, 2015.
2. "Life Cycle Assessment: Principals and Practice", EPA/600/R-06/060, May 2006.

3. Bell, Trudy, “Pipelines Safety and Security: Is It No More Than A Pipe Dream?”, http://www.tbp.org/pubs/Features/W15Bell.pdf The Bent, Winter 2015, pp. 12-19.
4. ABET, http://www.abet.org/etac-criteria-2015-2016/ 2015.
5. Dalrymple, Odesma, et.al, “The Motivational and Transfer Potential of Disassemble/Analyze/Assemble Activities”, JEE, October 2011, Vol.100, No.4, pp. 741-759.
6. Menekse, Muhsin, et.al, “Differentiated Overt Learning Activities for Effective Instruction ion Engineering Classrooms”, JEE, July 2013, Vol. 102, No. 3, pp. 346-374.

Appendix:
Life Cycle Analyses within Infrastructure Systems and/or Structures
Part 1: Defining a Part in a Large System and its Related Critical Material

Overview: In Part 1, we will identify a ‘material’ that may cause a ‘system/structure’ to fail. Please answer the following four questions (each is a task for you to do):

1) Identify and describe an appropriate structure or system of interest.
Examples: city gas supply, university power plant,

2) Pick and describe an appropriate part/device/component within your structure/system. However, you must pick a part that, if it fails, will cause the system to fail or stop operating.
Example: A bridge has reinforced columns and road decks, etc. If the columns fail, the bridge will fail. If the road deck fails (e.g. potholes), then the road is compromised.

3) With regard to a part causing the system to ‘fail’, you are asked to ‘rate’ the part both with regard to operation, and the system with regard to safety. Please note that this is discussed below. You are constrained in your choices. The part you choose must be at most an O3. This means that if the material of the part fails, then the system or structure will be compromised. Also, rate the system with regard to this ‘failing’ part and if it will cause the system to function in an unsafe manner. I recommend a five-star rating system with five being ‘best’.

4) Select one critical material associated with your chosen part. We will apply LCA to this material.
Example: A bridge column is made of steel-reinforced concrete. The associated critical material is the rebar (steel) used as the reinforcement.

Please keep your narration to one sheet of paper. I will specifically look for a defined system or structure. Then I will look for a critical part and how you rated its failure with regard to safety and function of the system. Finally, I will look for a defined material.

Part 1. Example

In this first part of our exploration into the 'Life Cycle' of a complex system, we should identify a system or structure of interest (e.g. its expensive and failing….). We have to describe it in a way conducive to preventing failure.

Thus, it is up to you to select a system or structure. Both guidance and examples are available, so please do not make excuses for any lack of progress. This world does not care if you are smart or careless or deceptive. In this course you are asked to engage in good academic work. Please read on.

Guidance: please think of newsworthy items that are appropriate to our needs. For example, in the summer of 2014 a 30" water main burst under UCLA. Twenty million gallons of water wrecked roads, card and buildings. What happened? The pipe failed. This is a materials failure that could have been avoided.

Another example: In 2011 the bridge over the Missisippi river on I-35 at Minneapolis MN collapsed killing over a dozen people. I grew up in this area and my sister should have been on that bridge but for a dental appointment. Why did it collapse? There appeared to be both a design flaw at the joints (they were not big enough) and a unique loading (construction material -sand- placed on the inside lanes during maintenance). This particular failure did not result from a material degradation scenario, so it would not be a good selection for the purposes of this activity.

In 2010 San Francisco had a 30” pipeline explode killing eight people. From Wikipedia: “In January 2011, federal investigators reported that they found numerous defective welds in the pipeline. The thickness of the pipe varied, and some welds did not penetrate the pipes completely. As PG&E increased the pressure in the pipes to meet growing energy demand, the defective welds were further weakened until their failure. As the pipeline was installed in 1956, modern testing methods such as X-rays were not available to detect the problem at that time. As you can read: there are big problems all over our planet.

There are so many failures occurring so often that there are plenty of systems to choose. The biggest issue we may have is obtaining information. For example, most power plant cooling towers have failed tubes. But the management does not want the stockholders or the consumers to know about it. Why? Because fixing these towers typically costs millions, and American companies do not include or plan for these costs (typically forecast over 90 days). So the operators ‘pinch’ the tubes shut, and the efficiency of the towers decrease. How long can this continue? That is a good question.

More examples include all roads, bridges, rails, power transmission, pipelines and energy systems. All structures and mechanisms are fair game, and you should be thinking of how consumer items are 'pitched' about lifetime and service.

Remember that Americans typically buy, use and toss products (typically into a landfill). But those in Europe and other more mature cultures typically recycle and reuse products as a norm. We, as a culture, have a hard time thinking ‘long-term’ (e.g. more than 90 day return on investment). But as noted above: people die from these oversights. Did you know that there is a 30” water line in Washington D.C., still in use, that was installed around the Civil War era? Yes, it is wood….

Notes on Ratings for ‘Safety’ and ‘Operation’:

There are some schemes already in place to help you. But it is interesting to note that there are no entries in Wikipedia for ‘Operational ratings’ or ‘Safety ratings’. So we will do the best we can. No amount of combinations helped me (e.g. device operation, pipeline operation, building operation, operation measures). So how about a search engine? Building ratings are well supported by ASHRAE’s ‘Building Energy Quotient’. But it is specific to buildings and primarily reflects operational efficiency. The UK has a nice assessment for pipelines (http://www.hse.gov.uk/foi/internalops/og/og-00037.htm). But this emphasizes management of the pipeline system. This is all industry specific effort and does not have the ‘global perspective’ that we need.

For both of these ratings, I then suggest we create a simple assessment that is easily understood and applied, such as the one to five stars so common in our culture.

For Structural and/or System Operations, with respect to a specific parts performance, please use the following metric.
O0, No Star = System does not work with this part.
O1, One Star = Will work once, maybe, but is expected to subsequently fail
O2, Two Stars = Will work repeatedly, in theory, but has no success history.
O3, Three Stars = Will work repeatedly with part maintenance, but has a limited lifetime.
O4, Four Stars = Will work indefinitely with part maintenance
O5, Five Stars = Will work indefinitely without part maintenance

For Safety of a structure or system: with regard to a selected part or device within that system.
S0, Zero Star: System is not safe. The system will cause harm if the specific part fails.
S1, One Star: System works once, but is considered unsafe and this part should not be used
S2, Two Stars: System safely works repeatedly, but part lifetime is unknown
S3, Three Stars: will work safely, repeatedly with part maintenance, but has limited lifetime
S4, Four Stars: will safely work indefinitely with part maintenance
S5, Five Stars: will safely work forever without maintenance

Don't be lazy: look up appropriate information yourself. Get used to doing your own research and forming your own opinions. That is what you will get paid for as an engineer.

Life Cycle Analyses within Infrastructure Systems and/or Structures
Part 2: Defining your Part and Material Maintenance

Overview: In Part 1, we identified a ‘material’ that may cause a ‘system/structure’ to fail or significantly reduce performance. In Part 2 we investigate the maintenance of that part and material. We need to know more about how failure occurs.

Please answer the following four questions:

1) Identify and describe the specific part and material that you wish to investigate. Please also identify who ‘owns’ or is ‘responsible for’ the part and system.
Examples: The City of xxxxxxx gas supply ‘residential supply shutoff valve’ has a brass gate.

2) Now describe a scenario in which this material and part fails, thus causing the system to fail or degrade operation.

Example: The gas valve breaks when a fireman tries to shut it off, allowing gas to continue into the structure and burn the house down.

3) Please describe how this material is put into (or associated with or attached to) the part itself.

Example: the brass is purchased as a cast part and assembled into the valve.

4) Please describe the current (if any) maintenance and inspection (if any) with which this part and material may be subject.

Example: A typical gas valve may never be touched after it is installed, but each time a residence is sold, there is an inspection of the system.

Please keep your narration to one sheet of paper. I will specifically look for part 'owners'. Then I will look for a failure scenario. I will look for any information on how the material is associated with the part, and finally I will look for information on the maintenance and inspection of the material and/or part.

Life Cycle Analyses within Infrastructure Systems and/or Structures
Part 3: Defining Aspects of the Cost of Part Maintenance/Inspection/Regulation

Overview: In Part 1, we identified a 'material' that may cause a 'system/structure' to fail or significantly reduce performance. In Part 2 we investigated the maintenance of that part and material. Now we need to know how failures occur or are prevented under an environment of oversight.

Please answer the following four questions:

1) Describe the Life Cycle of the material you chose.

Examples: The brass gate started out as a combination of copper and zinc that we cast into ingots. These ingots are purchased by a manufacturer (that produces wrought bars), and then perhaps sold again (where the bars are formed/machined into the final part). There may be another vendor that assembles the valves (the OEM: Original Equipment Manufacturer). Valves are typically purchased by an installer and then operated in a delivery system. Upon replacement or at the end of its lifetime, discarded valves may be recycled (e.g. melted into ingots) or buried in a landfill.

2) Now please describe the various 'stakeholders' of this part/material.

Example: The gate is owned by the City of xxxxxxx. But the valve is used by the residential property owner. Also, the operation of the valve is specified by the manufacturer (OEM). In some parts, the entire 'pedigree' (e.g. a list of every entity that touched the material/part) may be documented. This is common in the aerospace industry, where failures must be corrected quickly. An international method of regulating an industry in this manner is ISO (International Organization of Standards: iso.org) and in particular: ISO 9000.

3) How do these stakeholders interact when a failure occurs?

Example: If there is litigation involved, the failed part may be acquired by the insurance company. They would typically hire a lawyer, who would subcontract a professional engineer to investigate. If the failure was benign, then the 'operator' (City of xxxxxxx) would typically do an internal investigation to see if they could prevent future failures. The residential owner (if alive) would simply wait for the 'operator' to fix the system.

4) Please discuss the 'cost of your part/material/system failure?
Example: Obviously the gas valve would have to be replaced, since it failed, and there would be an associated part cost. However, if litigation was involved, the related 'cost' could be in the millions of dollars.

Please keep your narration to one sheet of paper. I will specifically look for how your material evolves through its use (LCA). Then I will look for 'stakeholders' and how they interact regarding system failure. Finally I will look for information on related 'costs' regarding the failure of your material/part.

Life Cycle Analyses within Infrastructure Systems and/or Structures
Part 4: Prevention of System or Structures Failures, and Related Costs

Overview: In Part 1, we identified a 'material' that may cause a 'system/structure' to fail or significantly reduce performance. In Part 2 we investigated the maintenance of that part and material. Now we need to know how failures occur or are prevented under an environment of oversight. In Part 3 we discussed costs of failures and how stakeholders were involved. Now, we discuss how to prevent these potential failures and related costs.

So for the final effort in this LCA Activity, please answer the following questions:

1) Create a maintenance/inspection/sustainable plan of your own.
Examples: The 'operator' (City of Exxxxxx) could propose to work with the fire department to do annual inspections of all residential gas supply systems (including the valves). This would mitigate the risk of valve failure and promote citizen relations.

2) Discuss the cost of implementing your plan, and how this cost compares to your previous explanation of related failure costs.
Example: Since litigation typically results in 'catastrophic' costs (e.g. millions), the relative cost of adding a routine inspection scenario to the duties of the fire department must be minor fraction. If the City has 1000 residences, and the fire department can inspect four per hour, then it would take 250 hours. Assuming 20/hour, this would cost $5000. If there was 'synergy' with the fire department (e.g. they have to do something all day…), then it may cost nothing.

3) Suggest an improvement to the system (outside of the your new plan, above).
Example: These shut-off valves are quite robust. A failure is usually associated with extreme corrosion, so placement and environment are concerns, if we choose to keep the same type of system. Another type of 'shut-off' is to simply 'pinch' the plastic gas supply line. This could be achieved by supplying the fire department with a tool for that purpose. With respect to risk, this

is a redundant method of shutting off the gas when needed (usually referred to as ‘comprehensive risk reduction’).

4) Please ‘reflect’ on this whole LCA Activity!
What part of the LCA Assignments was most enlightening or interesting to you?
How would you improve this LCA Activity?

Please keep your narration to one sheet of paper. I will specifically look for your new plan and its cost. Then I will look for your ‘improved’ system. Thank you for putting all this effort into helping preserve our infrastructure and standard of living!