A Course in Life-cycle Engineering

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ABSTRACT
This paper describes the development and implementation of a class in the mechanical aspects of life-cycle engineering. This course teaches students to use cutting edge design methodologies and analysis tools and apply them to the redesign of industrial products. The life-cycle engineering course benefits from recent advances in design education across the country and at The University of Alabama (UA). The course fills a gap in the set of analysis tools that students are given in their formal education.

1. BACKGROUND

This class in life-cycle engineering (LCE) is an outgrowth of the recent expansions and improvements in design education. One of these expansions, the use of industrial projects, is a cornerstone of the class. The course is naturally based upon the major principles of life-cycle engineering.

1.1 Design Education

For quite some time, there has been a push to improve the content and applicability of engineering design education. Spurred by changes in ABET certification criteria and an explosion in design theory and methodology research, some universities revamped capstone engineering design classes. Many mechanical engineering departments developed courses that require students to take products from concept to physical reality. These programs have been extremely successful. At The University of Alabama, we developed a two semester capstone experience which includes two separate but related classes. In the first class, students learn about the design process and basic design tools. Students practice incorporating traditional engineering analysis into the creative process. In this class, the students go through a team-based, concept to physical reality product development process in a competitive environment. Our students tackle the development of novel, client-requested assistive technologies and have even implemented the finished products for clients. Projects are suggested by local "clients" who, receive the products at the end of class for their personal use. Past projects have included rain shields for wheelchairs, devices to load wheelchairs into the back seat of a two door car, and wheelchair attachments to allow clients to stand up. This class teaches the students to use a structured design process, gives them confidence in their ability to finish the product development, and allows them to interact with clients. In the second capstone class, students spend the entire semester completing an industrially sponsored design project. Each student group is given a different paying client who has clear objectives for the students to meet by the end of the semester. This class increases the students' self-confidence and gives them a realistic trial run in product development and engineering analysis before they graduate.

These two classes have served the students and the department well. The design classes have gained regional recognition for their ability to yield “finished quality” products that are implemented. Students’ rigorous engineering analysis coupled with their creativity have made these projects successful. However, there is something missing from this design experience. In an article on the state of mechanical engineering design education Dixon states that,

> *“...the only design evaluation criteria expected to be involved are technical engineering criteria, whose values are generally computable by application of engineering science principles...[D]esign evaluation must include cost, manufacturability, marketing, and other factors in addition to the functional and technical issues that can be analyzed using engineering science...By limiting design education to technical design issues, we omit the rest of the engineering design process...[S]tudents learn very little about the current methods used in industry to apply the principles of these engineering sciences in real design or analysis situations.” (Dixon, 1991)*

The goal of the life-cycle engineering class is to teach students the tools and methodologies necessary to perform this more complete design evaluation.

1.2 Life-cycle Engineering

Life-cycle engineering is a methodology of incorporating a product’s life time values at the early stages of product design (Barkan, 1988). These values include not only functionality but business concerns, production, assembly, service, product retirement, and any other requirement put on the product from conception to grave. Figure 1 shows how the life-cycle design process is a process where life-cycle concerns are taken into account from the very beginning through iterative life-cycle analysis and redesign until a final solution is closed in upon. Perhaps the most mature area of life-cycle engineering is Design for Assembly (DFA). Boothroyd and Dewhurst (1985), Sturges (1992), and Miyakawa (1990) have proven that DFA can lead to significant savings during production. Research into other aspects of life-cycle engineering includes producibility (Poli, 1991), serviceability (Gershenson, 1991; Makino, 1989), and product retirement (Navinchandra, 1994; Burke, 1992).

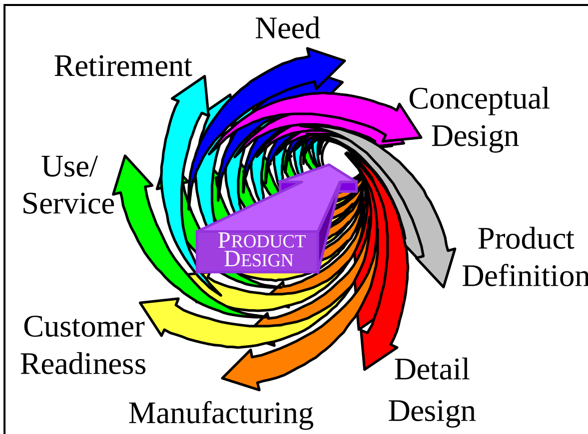


Figure 1: *The Product Life-cycle in the design process.*

Life-cycle engineering has gone through a boon in the last twenty years. However, many of the advances in life-cycle engineering have been slow to make it into the mechanical engineering curriculum. The most common life-cycle characteristic in mechanical engineering curricula is manufacturing. At the University of Massachusetts in Amherst, they have incorporated design for manufacturability into the freshman design curriculum. At many other universities there are sophisticated manufacturing process classes and at some there are design for manufacturability classes at the graduate level. Stanford University’s design for manufacturability class is broadcast across the country. The class, developed by Kosuke Ishii and based upon a similar class he developed at Ohio State University, covers more than just manufacturing but the impact of design decisions on manufacturing is the primary concern. This course uses one or two large scale, industry sponsored design projects. While this format is extremely successful at Stanford, it requires enormous funding and two courses to teach the life-cycle engineering principles. Neither the resources nor the time are available at most universities.

2. CLASS FORMAT

The educational goals of the LCE class are twofold: 1) to teach students life-cycle engineering and cross-functional teaming and 2) to increase the interaction among undergraduate students, graduate students, faculty, and industry in an applied academic situation. This class has worked due to the variety of topics and instructional methods. The syllabus is quite varied in its content while focusing on Life-cycle Design. The lectures are interspersed with design reviews of industrial products and example products. This mixture of classroom activities, coupled with a strong interaction with industry and a mix of seniors and graduate students, has led to exciting and varied classes.

2.1 Syllabus

The LCE course familiarizes students with the principles and techniques of life-cycle engineering. These techniques include design reviews, reverse engineering, value engineering, cost/benefit analysis, life-cycle, and modular design. Upon completion of this combined undergraduate/graduate course, students are adept at weighing the costs and benefits of product design decisions as they apply to the entire life of a product from concept to retirement. A secondary objective of this class is the improvement of the life-cycle design of industrial products supplied by sponsors. The product improvement is accomplished through a series of design reviews. Ten to fifteen industrial products in need of redesign are solicited for each semester. Each product has a perceived, specific life-cycle deficiency that the industrial sponsor wants corrected. The class, as a whole, spends roughly one week improving one product as a way of learning the tools that are applicable to that life-cycle characteristic. The outputs of this process are a concise memo and drawings detailing the class redesign suggestions. Industrial sponsors respond to the students' memo, discussing the merits and faults of the suggestions.

The specific topics in the syllabus for the class are:

1. The Life-cycle
2. Concurrent Design Teams
3. Design Reviews
4. Design for the Market
5. Value Engineering
6. Design for Function
7. Relative Worth Analysis
8. Cost/Benefit Analysis
9. Design for Production
10. Design for Assembly
11. Quality/Inspection
12. Human Factors Design
13. Reliability Design
14. Serviceability Design
15. Design for Product Retirement

Typically, people discuss the life-cycle as beginning with production or, at the earliest, prototyping. However, business and marketing issues are important in the education of future design engineers. To impress this upon students, the first 30 percent of the class concentrates on these "up front" product development issues.

The lecture on the Life-cycle of a product gives students an overview of the phases a product goes through in its life and what are the impacts of that phase on the cost to the manufacturer and satisfaction of the consumer. A brief amount of time is then spent discussing the role of Concurrent, or cross functional, Design Teams and how they can conduct efficient Design

Reviews. The concepts of team play, objectiveness, and trade-off analysis are detailed and the methodology behind concept selection is discussed and applied. Design for the Market allows the engineering students to understand the pressure that marketers face in developing and integrating customer's needs. The ideas of focus groups, elicitation techniques, market strategy, and market segment are discussed from the stand point of "How do they affect product design?" One important facet is teaching students the difference between consumer requirements and engineering requirements. As an example, consumers may ask for a laser printer which loads paper like a CD player loads a single CD. However, this is not the true root of the need, this is only their idea for a solution. The true need may be that they dislike having to load the paper under the paper guides or dislike having to remove and replace the paper tray. Value Engineering is a broad topic pertaining to ensuring certain qualities or values are present in the final product. In the LCE class, we discuss some of those tools including a brief review of Quality Function Deployment and value graphs and trees. Value graphs and trees are used to understand what values are necessary and to brainstorm different concepts that incorporate these values. The design for function topic includes practice in brainstorming several ways to accomplish a single function without getting too wrapped up in the particular components. This brief discussion is followed by a significant amount of class time spent discussing and applying the concepts of Relative Worth Analysis. The basis of this concept is measuring the costs involved in implementing a particular value or function in the product. Relative worth analysis prepares the class for a discussion of formal cost/benefit analysis. Cost benefit analysis encourages engineers to try to quantify, when possible, the financial benefits of design changes and to weigh these against the costs.

Following the lectures on and applications of these "up front" product development issues, the remainder of the class concentrates on issues more commonly associated with life-cycle engineering, not common in many design curricula. This section of the class begins with a lengthy discussion and application of the principles of Design for Production. Sometimes called design for manufacturability or DFM, this topic can have the greatest impact on product life-cycle costs. Time is spent discussing various manufacturing processes and comparing their costs and applications. Included in this discussion is a discussion of plastics. This is a topic that is not frequently discussed in curricula, but it fit very well with one of the redesign projects we conducted. Complementing the discussion of DFM was a discussion and thorough application of Design for Assembly, DFA. DFA is the best defined and researched of the life-cycle areas and we discuss primarily three DFA tools: Boothroyd and Dewhurst's method (Boothroyd and Dewhurst, 1985), the GE methodology (Sturges and Kilani, 1992), and the Hitachi Evaluation Method (Miyakawa, *et al.*, 1990). Students appreciate the very quantifiable nature of this topic, but they are warned that the quality of the results depends upon the quality of the input. A brief discussion of Quality and Inspection methods is included after the DFA module. While no applications are used, it gives the students a better understanding of an important life-cycle characteristic. Human Factors Design, allows the students to once again focus on the end user. In this module, the class discusses anthropometry, human-product interfaces, and safety. The applications of these topics are usually very interesting and have a strong impact on students' work in other classes. Reliability Design is taught in a somewhat cursory fashion due to time constraints. However, we do discuss component architecture, bathtub curves, and statistical reliability.

Once again, the discussions are from a design for "X" standpoint. Therefore, we look at how to increase reliability through redesign as well as how to find reliability problems. Failure modes and effects analysis (FMEA)(Cite) is one of the tools used in this module. While DFM and DFA are common to life-cycle engineering discussion, Serviceability Design or DFS, is not usually included. DFS is more common in military applications, but it has been adopted by the automobile industry and others. The main tool used for analysis in this module is service mode analysis (SMA)(Cite). SMA is similar to FMEA in that it is a way to organize information in a meaningful way to find problems in a product's design. It's benefit lies more in the redesign implications than it's ability to quantify serviceability. The last topic in this curriculum is Design for Product Retirement (DFR). DFR is thought of in many different ways. Within this curriculum, we take a narrow view in that we only discuss the end-of-life strategy of the product and how to design a product to best make use of each particular strategy. The four main strategies, from worst to best, are: dispose, recycle, remanufacture, and reuse. We do discuss environmental impact and product reduction briefly, but we concentrate on designing products that are easily, cheaply, and safely retired.

As one might guess, there is no one text that effectively covers this range of topics from a product design standpoint (although Ulrich, 1995, Love, 1986, and Prasad, 1996 are very good). While this can be a problem, it yielded a sense of freedom in developing lectures. The material could be extremely flexible, topical, and timely. Therefore, in developing the curriculum, great care was taken in lecturing on material from many different sources. Some sources were available in published texts, however, many were only available through current journals or information from web sites. Additional information was culled from a course which covers some of the above material taught by Kosuke Ishii at Stanford University. This graduate course in design for manufacturability is based on a similar course taught by Dr. Ishii at Ohio State University. Both of these courses served as inspirations for the current class at UA.

2.2 Class time

The LCE class time is split evenly between lecturing, applications, and design reviews. The lectures introduce the students to the material and the analysis tools, the application examples and industry examples allow students to step through the use of the tools with and without guidance from the professor, and the design reviews allow the students to decide which of their ideas will represent the class. Each type of class period is singly important but all are strongly interdependent.

Lectures are used as the format to teach background material and introduce students to new concepts and new analysis tools. There is an unusually large proportion of material based on industrial uses of life-cycle engineering and the current research into life-cycle methodologies and tools. The goal is to give students cutting edge information that is not available at most companies or in most curricula. One noticeable addition to lectures is the interactive nature of the information delivery. While students are not expected to volunteer much of the background material, they are expected to assimilate the information quickly. To help this process, the lecture is peppered with questions such as, "Why is this important?", "Why is this step/tool necessary?", and "What are some examples of this?". The last question specially adds to the richness of the lectures. The examples that the students give for the background knowledge are a learning experience for all, including the professor. The breadth of examples exhibit how people from different backgrounds bring different things to a learning situation.

Due to the novel nature of the topic, frequent breaks are taken within the material to discuss where we are in the life-cycle and how what we are discussing affects past material. This association is done by the students with prodding from the faculty in the form of questions such as, "How does this complement the other tools we have used?", "How could this help an engineer in a design review?", and "Do you think this tool saves time or wastes time?". This association has definitely added meaning to the material by allowing the students to organize the material in their own words. One important part of teaching this type of material has been convincing students that each of the tools is both useful and used in industry. To aid in this, it is important to show industrial applications of all applicable tools and methodologies. Some of these examples can come from the students but most of these come from the industrial experience of the faculty and available case studies. These cases help solidify the ideas in the students' minds.

After the background, analysis tools, and methodologies are presented and discussed, class time is given over to allowing students to carefully step through the use of this knowledge. The common teaching scheme used is to let students step through the analysis slowly, partially with the professor and partially on their own. This scheme is accomplished by proceeding with example applications with part of the analysis done in class with faculty prompting and part of the analysis done at home and discussed in class. Due to the student make up of the class, students are given quite a bit of leeway to learn at their own pace. The example products are items from around the house or laboratories, because only one product is recruited per life-cycle characteristic and because there is a lack of expected success in the initial analysis/redesign trial with new tools and methodologies. Household items insure student familiarity. The items include children's toys, hardware, appliances, car parts, computer parts, and sports equipment. In addition, students are often asked to bring in their own items for analysis. Students' items include items from their homes, their hobbies, and their student projects from other classes.

The last manner of teaching used in the class is design reviews. Design reviews of the *industrial* products involve the entire class acting as a single design team. Before the design reviews, students conduct extensive life-cycle analyses on the industrial products. These analyses are performed using single life-cycle characteristics and include multiple suggestions for redesign to improve the life-cycle "goodness" of the product. During the in-class design reviews, students explain, defend, and compare their redesign suggestions. These reviews often take longer than a period and are often exercises in controlled anarchy. It takes students the better part of the semester to learn that redesign ideas given during the design reviews immediately become the property of the entire design team. As such, all redesign ideas must me evaluated objectively by all participants. It is not easy for anyone to give up ownership of their own ideas. As the semester progresses, less and less moderation is needed from the professor. In addition, and more importantly, students learn to back good, creative redesign ideas with numbers and information from appropriate analysis tools which were not previously available to them. These are tools that have not usually been available to design engineers either. As the semester progresses, multiple life-cycle viewpoints are considered simultaneously.

Grading is a necessary part of teaching. It was necessary to construct a grading scheme that would encourage students to participate in all forms of class periods. By making informed participation a part of the grade equal to out of class assignments, students have been, if anything, over zealous in their class participation. Constant reminders that it is *informed* participation, and not just random participation, that furthers the class are necessary in the first few weeks of the semester.

2.3 Industry Interaction

One of the best experiences the students have in the LCE class is interacting with industrial contacts through memos. Graduate students are responsible for writing memorandums to industrial contacts summarizing the classes' redesign suggestions and supporting analyses. Of these memos, the best is chosen to send to the contact. The contact, in turn, is responsible for responding to this memo. Responses are in the form of a memo stating their comments on the students' suggestions. Contact comments are often similar to "…this suggestion is useful, something we will pursue" or "this suggestion is creative but you have not taken into account requirement X." Students enjoy the immediate feedback afforded by faxing the memos back and forth to the contacts. The immediate feedback makes it seem like the contact is actually part of the class.

3. PROJECT RECRUITING

The industrial projects used in the life-cycle engineering class are very different from those used in industrially-based design classes. The students' redesign efforts are concentrated on only one life-cycle characteristic at a time and, while the effort is concentrated, students work for a maximum of two weeks on any one product. The short but specific projects allow the application of the tools to be the focus of the class and not the product. This concentration necessitates industrial products with well defined and specific problems. Due to the time spent, fewer promises are made to industrial partners and therefore no financial commitment is necessary. However, the shortened redesign cycle does not diminish the benefits to the students, the department, nor the sponsor.

The projects solicited for the life-cycle engineering class are recruited for the life-cycle characteristic of interest. Each product must have one particular life-cycle characteristic which the sponsor wants addressed. While some products can be used for redesign in more than one life-cycle characteristic, that is not ideal. The goal is to give students one or two example applications for each life-cycle analysis tool or methodology. Sponsors are told that improving the industrial products is a secondary goal of the class. This usually weeds out the less interested sponsors but those that remain are more understanding of the teaching mission and more apt to pick appropriate products and appropriate contacts.

Given the limited scope of the redesign project, there must still be a definite need on the part of the sponsor for a redesign. The project must be of sufficient interest that the problem is well defined and the contact is eager to participate. The contact will usually spend several hours formulating the problem, some time delivering example products, one hour developing background information for the class, and two hours responding to the students' redesign suggestions. This time is not available from someone with little interest in the project. In addition, it there is no interest on the part of the sponsor, the project will usually not be of sufficient interest to the class.

The last requirement for a good project is that the sponsor understand the limited time and capabilities of the class. Given the limited time and limited resources available to the students, the redesign suggestions are strong on innovation but short on traditional analysis. For this reason, the life-cycle engineering is free to participating companies. Example products, when necessary, are donated by the sponsoring company. In some cases this cost is nominal as in the case of a beverage can manufacturer or a fence stretcher manufacturer. However, in some cases the costs have been quite significant as in the nearly $3,000 an automobile manufacturer spent to write off and deliver car doors. The other major cost to the sponsor is the time of their contact. As previously discussed, the contact will spend roughly one day with project.

4. EXAMPLE PROJECT - CAR DOOR REDESIGN

To give a better understanding of the work done by the students on the industrial projects, one project necessitating the analysis and redesign of an automobile door based upon serviceability needs is described below. The goal of this project was to use the redesign of a car door for an automobile manufacturer to teach students about how to incorporate serviceability requirements. Students performed a Service Mode Analysis (SMA) (Gershenson and Ishii, 1991) on the car door to decide what components were in need of redesign. The SMA was based upon the manufacturer's data on the most common service procedures for the particular vehicle. The understanding of how the repairs impacted the product's components and how frequency and cost of particular "service operations" were related to components is the goal of SMA. One of the outputs of a thorough SMA is a list of "bottlenecks" that are in need of redesign. The project is best described by the sections of the memo sent to the manufacturer shown below.

Thank you for taking the time to respond to our design suggestions for the car door. After spending several hours dissecting and analyzing the door, the class of 26 students all participated in a design review in which we each presented suggestions for improving the overall serviceability of the door. Below are the most practical and feasible of those suggestions with all necessary information.

The class performed a detailed analysis of the Cadillac door with respect to its life cycle design for serviceability. The function tree for the door was generated to have a better understanding of the overall functioning of the automobile door and the criticality of each of the subassemblies and parts. For this analysis, we primarily focused on the DPTV's (Defects Per Thousand Vehicles) provided by the manufacturer.

<u>*Top 10 DPTV for Right Front Door:*</u>

1. *Door Assembly (Alignment)*
2. *Striker*
3. *Lock Actuator*

4. *Window Glass (Alignment)*
5. *Door Handle*
6. *Hinge (lower)*
7. *Hinge (upper)*
8. *Lock Rod*
9. *Lock*
10. *Window Regulator Motor*

Next, we performed a Service Mode Analysis for each of the DPTV's. The Service Mode Analysis examines customer impact as a result of a service mode. Customer impacts ranged from minor inconvenience to major hazards needing immediate attention by a trained technician. The next step was to determine the service modes. Because problems can stem from any number of things, this column of the chart had to be limited. Diagnosis for each service mode was based on experience as well as sound engineering judgment.

The next step taken in the analysis was to identify the service operations required to correct the service mode. We used the Service/Repair Manual, provided by the manufacturer, to determine the steps required to fix the problem. Service steps for the DPTV's were, for the most part, minor (e.g. removing bolts, installing, disconnecting).

The next thing performed was a Service Evaluation Analysis. This analysis concentrated on diagnosis and repair of service modes. Diagnosis and repair were broken into various categories (tools required for repair, training needed, method of detection, part cost, and part availability). For each category, a numeric value was assigned. Based on this numeric value, the mode of service was considered to be easily serviceable, average difficulty to service, or hard to service.

10 Most Costly Service Modes

1. Door Assembly (Alignment)
1. (tie) Lock Actuator
1. (tie) Door Handle
1. (tie) Lock
1. (tie) Window Regulator Motor
6. Window Glass (Alignment)
6. (tie) Lock Rod
8. Hinge (lower)
8. (tie) Hinge (upper)
10. Striker

Finally, the frequent appearance of labor operations in costly, imperative, high frequency service modes was probed. The resultant labor operations, termed service bottlenecks, were those most in need of redesign.

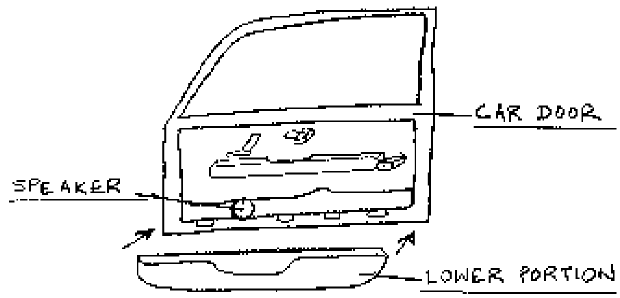
Bottlenecks : *The various bottlenecks are explained below in the order in which they are encountered during the serviceability evaluation methodology.*

1. *Exterior Panel (the outside, visible panel) - This panel must be removed in the servicing of any part with exception of the striker. However, this panel has already been designed for easy removal and is therefore not a great time problem.*
2. *Air Bag - The air bag must be removed in order to remove the rain cover, which would then allow access to the interior panel.*
3. *Water Deflector - The water deflector must be removed to gain access to all parts except for the striker. Once the water deflector has been removed, access can be gained to the outside door handle and lock cylinder.*
4. *Interior Panel (red plate) - Although some parts are located on the outside of the interior panel (motor, actuator and lock rods), others can only be accessed by removing the interior panel.*
5. *Different Bolt Types and Sizes - There are three different types and sizes of bolts that each require a different tool for removal: 7mm hex head bolt and nut, 10mm hex head bolt and nut, and star screws.*

Redesigns of the above bottlenecks were conceptualized and are discussed below.

Door Panel

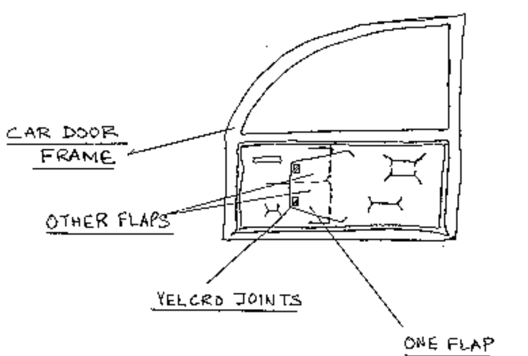
The door panel functions as an aesthetic cover to the interior mechanisms of the door. It also provides functions like a magazine holder pocket, a handle to pull the door and other control functions for windows, locks and accessories. The door panel is a multi function part in the door and the redesign involves breaking up the functions to provide more access to serviceability. The redesign will break the door panel into two parts. The lower section of the present panel will not be an integral part of the new design. First the panel is snapped onto the door. Then the lower portion will be snapped onto the panel separately.



The lower part is not a load bearing section. Thus the redesign will not affect the functionality. Also, dividing the panel will give easy access to the speaker in the door. The bottleneck of the door panel for repair of the speaker is thus eliminated. An additional improvement could be easy access to the lower part of the door frame. Easy tool access from the lower end could help in some other service areas.

Another design suggestion presented in class aimed at reducing the number of plastic clips on the door panel to reduce assembly time and service time. The new design will use 4 or 6 big plastic clips along with other fastening mechanisms like screws, pop-in snap fasteners or velcro to hold the door panel on the frame. If there is need we can redesign the existing plastic clips for more strength.

Water Deflector



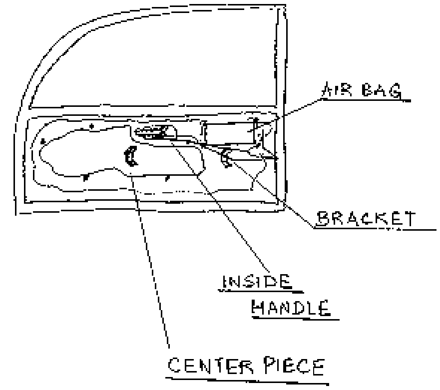
(LINES REFER TO CUTS ON THE DEFLECTOR)

The water deflector is another bottleneck in the service design. It has to be removed to access any part in the door assembly. The new deflector will also be one piece like the existing design at the periphery but the inside will consist of two flaps overlapping one another. The flaps will be held by small pieces of Velcro at the edges to facilitate the installation of the panel on the deflector. By pulling open the flaps we can have access to many of the parts in the door. This will help in eliminating the need for removing the deflector in all the service applications.

Another solution is having a border around the shield that would fasten to the door it the same way that car weather-strip does, with male and female ends. This "Ziploc" approach would be easily removable and replaceable and would improve the seal over the current method. This also reduces the service step of applying sealant after every service to the door assembly interior.

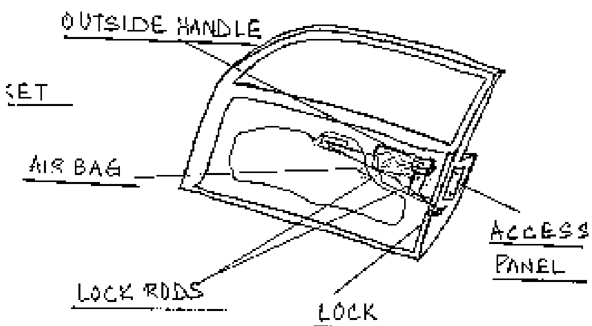
Center Piece

By removing the inside handle and the lock lever from the center piece and putting it on the frame we can effectively redesign the door for serviceability. This design change will reduce the size of the center piece and thus make access for the window regulator channel and the outside door handle. For most cases of service, the center piece will no longer have to be removed in order to service the door handle or work on the window regulator X-frame. It will also reduce the number of parts on the center piece and thus make it easier to handle and service.



Outside Handle

The outside handle is a high DPTV component. To service the outside handle each bottleneck is encountered. The new handle design allows for installation without the removal of the door panel and the water deflector. The new handle will have hidden bolts under the open/close flap that will allow it to be assembled from the outside and will not be an aesthetics deterrent. To connect the lock rod and the other rod to the handle, the design provides an access panel on the side post of the door. The panel will be installed with screws. It will be large enough for a person's hand to enter and perform necessary tasks. With this design change, we eliminate many bottlenecks in the service of the handle. These parts are now more accessible to the operator and the service will require much less time.



Wiring Harness

The wiring harness in the door assembly is another bottleneck. The design idea to eliminate this bottleneck uses a mother board inside the door assembly which will hold all the wiring connections on it. Connection and disconnection will be easier and will require less time making it a better design for serviceability. The mother board can be assembled in the door frame after considering its location importance.

Another use of the mother board can be in the door lock mechanisms. The mother board can be designed to hold the lock rods on it. Thus making it easy to access the lock rods for service of the door handle or the lock assembly itself.

5. CONCLUSIONS

This paper presented the possibilities for an upper level class in Life-cycle Engineering. The ideas presented are just a beginning. There is a definite need for this type of introduction to cross functional teaming and trading off multiple life-cycle viewpoints. Comments from the students have backed up these beliefs. Students have asked to make this a required class for future students. Industry has been very excited by the possibilities of both participating in and benefiting from this class. Several students have been hired as a direct result of the class and the number of willing sponsors is growing. Lastly, the students have begun to apply what they learn in the Life-cycle engineering class in other design classes they take. This has lead to a marked increase in quality of their finished products. This has been met with increased regional media coverage of their efforts. Additions for the future of this class include web-based communication, increased role from other engineering and non-engineering academic units, and a richer variety of teaming activities.

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