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USING PRODUCT ARCHITECTURE-BASED DESIGN METHODS TO GET SMART IN THE BATTLEFIELD

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Abstract

At the University of Missouri-Rolla, a novel product architecture design method was utilized to create new designs and prototypes of an intelligent battlefield hazard marking system for the United States Army. This design project was initiated by the Army to improve the current marking system in use worldwide. Designs and prototypes were submitted by three independent interdisciplinary teams of senior-level engineering students. Each team followed a procedure of customer needs collection, functional modeling, concept proving, and alpha and beta prototyping to arrive at their final design. Even though each design team was given the same problem statement and customer needs and followed the same design procedure, each team arrived at a unique final design. By using a functional modeling based product architecture method in their design, the three final designs, though unique, exhibited similarity in terms of a modular design.

Keywords: Concept Generation/Evaluation, Creative Design, Customer Needs, Innovation Methods

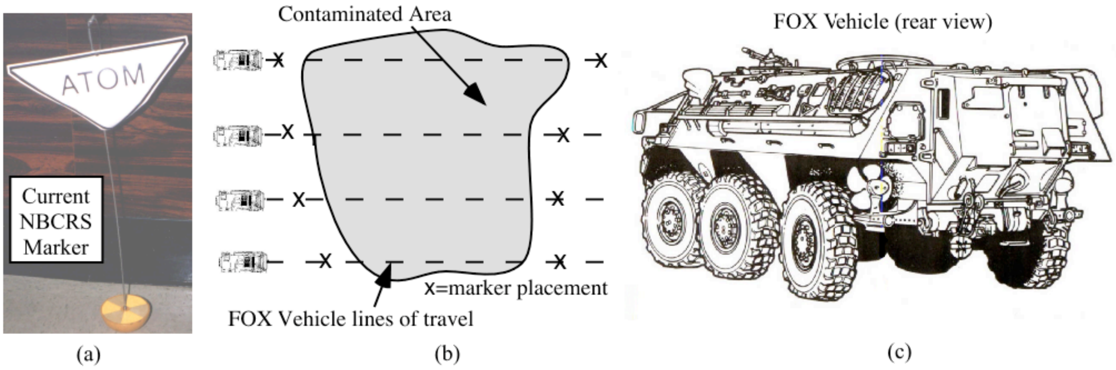
1. Introduction

The design of an intelligent battlefield marking system, otherwise known as the “smart marker”, was based around the use of a unique conceptual Design for Assembly (DFA) method. This DFA method is unlike traditional methods because it was initiated in the earliest stages of design. The ability to apply DFA techniques in conceptual design potentially eliminates the need for costly redesigns and shortens the time necessary for the overall design process. The product architecture-based conceptual DFA method (PACDFA) [1] can be applied in conceptual design because it requires only a functional representation of the product being designed. The PACDFA method identifies potential product modules (i.e. architecture) and then guides the designer to search for minimal part count solutions for each module. By not relying on a physical model of the system for its analysis, PACDFA is able to influence the assemblability and modularity of the *initial* physical representation of the new product.

In this paper the PACDFA method is applied to a joint design project between the United States Army and the University of Missouri-Rolla using the conceptual DFA method. Section 2 explores the background information for this project. Section 3 describes the methods used in the design project. Results of the project are presented in Section 4. The article concludes by applying the project results to a validation of the product architecture design method in Section 5.

2. Background

Since 1917 the United States Military has used devices similar to the one seen in Figure 1(a) to warn their personnel of potentially hazardous areas within a battlefield. Over the years, similar marking devices have been adopted by global agencies such as NATO. These devices, referred to as “markers,” consist of a weighted hemispherical base, a steel wire mast and a triangular vinyl flag and stand approximately one meter in height. When used in the Nuclear Biological Chemical Reconnaissance System (NBCRS), the markers are deployed around the perimeter of a hazardous area by a hazard detection vehicle in the manner shown in Figure 1(b). The FOX vehicle, shown in Figure 1(c), deploys the markers when it detects a hazardous area. The marker is deployed through a chute in the rear of the FOX vehicle and is intended to “upright itself” after hitting the ground. It is intended that personnel in the battlefield will see the markers and remain clear of the hazardous area.



(a) (b) (c)

Figure 1. NBCRS marking scheme.

Technological advances in the rest of the military have rendered this system of hazard marking obsolete and dangerous as a marking technology. The main problem with this antiquated method is that in the battlefield, it is common for the markers to be obscured from sight. This can occur when they are deployed in an area of tall undergrowth, but more commonly occurs when the marker is deployed on terrain where it cannot right itself. When the marker cannot be seen, it is not serving its function of hazard notification. Another drawback of this system is its limited communication capabilities. When deployed, it is important that the markers convey important information to troops in the area, but the NBCRS system cannot adequately accomplish this function. The only information that can be communicated with this system is that which can be written directly onto the vinyl flag. This form of information transfer necessitates that personnel be in very close proximity to the hazardous area in order to get this vital information. This could put them in a dangerous situation and is also quite time-consuming.

To improve this system, the Army has developed a list of customer needs for a new hazard marking system. The new system is necessary to improve the safety of their personnel by utilizing modern technologies to enhance the visibility and add communication capabilities to the marking system. The Army stipulates that the new marking system should utilize infrared and RF forms of wireless communication as well as a serial connection with which to download information onto the new “smart marker.” It is desired that this device be capable of storing and communicating one page of text and one page of graphics. Visible light and IR beacons are required to enhance the visibility of the new marker. The new system should also utilize global positioning satellite (GPS) technology to allow for better accountability and tamper resistance. In addition to these communication and visibility requirements, the marking system must be safe and easy to use. Finally, the new system must be compatible with the current FOX vehicles and must also be rugged enough to withstand the rigors of being deployed on a live battlefield. This new system of battlefield hazard marking is referred to as the “smart marker” system, because of its inherent data processing and communication capabilities.

This design project was administered by two faculty members of the Basic Engineering Department at the University of Missouri-Rolla [2] through two course offerings entitled *Engineering Design Methodology* and *Engineering Design Projects*. These courses brought mutli-disciplinary engineering students of senior status together for a capstone design series. The first course in the series exposed the students to various classical and modern design methods and the second course applied these methods to the design of the smart marker for the Army. The product architecture-based design method [1] was the appointed method for use in conceptual design stage of this project.

PACDFA is essentially a Design for Assembly (DFA) method for use in conceptual design. DFA is a design theory that analyzes product designs to improve assembly ease and reduce assembly time, typically through part count reduction [1, 3]. Since most DFA techniques can only be applied after the design geometry has been determined or a physical prototype is developed, they require multiple design iterations before any improvements, with respect to DFA, can be realized. Using this new method to apply DFA analysis in conceptual design makes for a more DFA-friendly product earlier in design than with traditional methods. Moreover, this approach has the ability to reduce time necessary to complete the design cycle, which was necessary in this project because of the short design-to-fabrication window. In the smart marker design project, final prototypes were required seven months after the customer needs declarations were made.

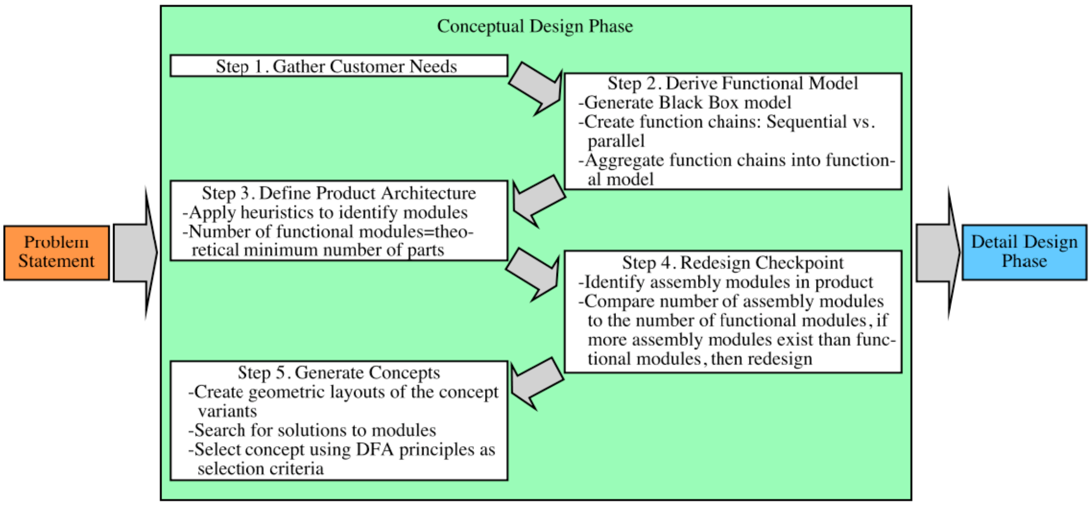


Figure 2. The product architecture-based approach to DFA.

The procedure for using the product architecture-based design method can be seen in Figure 2. PACDFA uses a functional representation of a new product to define a modular product architecture during the earliest stages of the design process. Modular product architectures can offer distinct advantages during manufacturing and assembly [4]. Another advantage of a modular product architecture is that they easily lend themselves to the definition of product platforms and families [5-16]. In the PACDFA method, the product architecture for the new product is defined based on identified modules from the product's functional model using a module heuristic approach [4]. A functional model is a graphical representation of the desired functionality of the new product and assumes no physical form for the design [17]. Thus, this method can be applied before physical design prototypes have been made, potentially eliminating the need for multiple redesigns. In this project the functional basis, a standardized vocabulary for use within functional modeling, is used to derive, and improve the method's repeatability among different designers [18].

3. Approach

Within the *Engineering Design Projects* course, three design teams were assembled with 4 to 5 members in each team. The teams were comprised of mechanical engineering, electrical engineering, computer engineering and engineering management seniors. These design teams worked independently in the design of the mechanical prototypes of the smart marker, so that three different physical prototypes would be submitted to the customer. A standard electronic/wireless communication module for the smart markers that interfaces with all three mechanical designs was selected due to the stricter Army requirements on that subsystem. To accomplish this, the electrical and computer engineers would also work in a separate design team concentrating on this module. All of the teams followed the product architecture method in the conceptual design of their marker and shared similar overall design procedures [2].

Each team initiated their design process by conducting interviews with the Army to determine customer needs and their associated weights [17]. The teams then used the customer needs to guide their development of a functional model for the smart marker system. This functional model can be seen in Figure 3. Developing a functional model that completely and accurately depicts a new product's desired functionality while satisfying the customer's desires is a key element in the design of a successful product. The functional model is also of utmost importance to the PACDFA method, as it is used to determine modules for the new design.

As prescribed by the PACDFA method, the heuristics of Stone et al. [4] were applied to the functional model of the smart marker design in order to identify the functions that should be aggregated into modules. The modules identified by this process can be seen in the functional model in Figure 3. Eleven modules were defined for the smart marker conceptual design. Table 1 shows the identified modules and the functions that they contain.

After defining a modular product architecture, each team followed a procedure of concept generation and testing. In this step, each design team derived morphological matrices [17, 19-21] to enumerate physical embodiments of their modules. Each team then developed their own selection criteria to choose the best physical embodiment concepts. After narrowing the number of solutions, mathematical models and proof of concept models were developed and evaluated to refine the selected modular concepts. In addition to the ability to perform this analysis in conceptual design, the modular nature of the PACDFA approach also afforded the design teams convenient boundaries for distributing tasks. In component design and fabrication, it was common for the design teams to delegate tasks based on the relationships from the product modules. At this point, customer impressions of the proof of concept models were gathered and necessary modifications were made to the module concept variants.

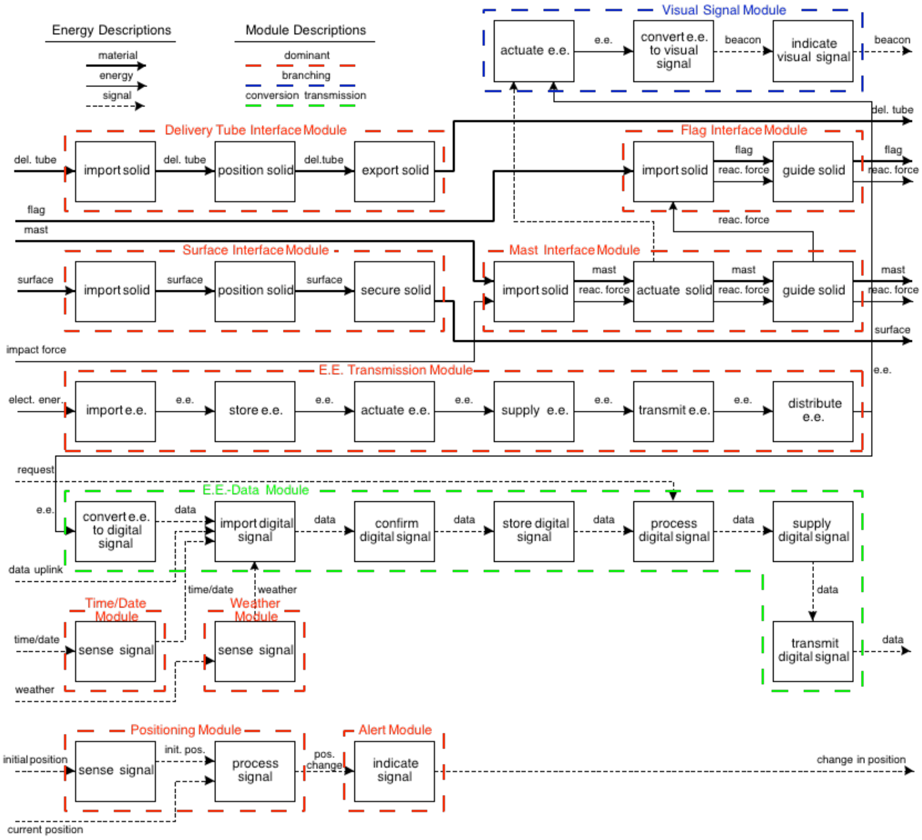


Figure 3. Smart Marker functional model with modules.

Table 1. Smart Marker modules.

Module	Module Type	Associated Functions
Alert Module	Dominant Flow	Indicate Signal
Delivery Tube Interface Module	Dominant Flow	Import Solid, Position Solid, Export Solid
E.E. Data Module	Conversion Transmission	Convert E.E. to Digital Signal, Import Digital Signal, Confirm Digital Signal, Store Digital Signal, Process Digital Signal, Supply Digital Signal, Transmit Digital Signal
E.E. Transmission Module	Dominant Flow	Import E.E., Store E.E., Actuate E.E., Supply E.E., Transmit E.E., Distribute E.E.
Flag Interface module	Dominant Flow	Import Solid, Guide Solid
Mast Interface Module	Dominant Flow	Import Solid, Actuate Solid, Guide Solid
Positioning Module	Dominant Flow	Sense Signal, Process Signal
Surface Interface module	Dominant Flow	Import Solid, Position Solid, Secure Solid
Time/Date Module	Dominant Flow	Sense Signal
Visual Signal Module	Branching	Actuate E.E., Convert E.E. to Visual Signal, Indicate Visual Signal
Weather Module	Dominant Flow	Sense Signal

Each team designed and fabricated alpha prototypes by embodying their selected modular concept variants into a first overall physical prototype. Each team's alpha prototype can be seen in Figure 4. Team 1's alpha prototype utilizes a horizontal cylindrical base design with a rotating counterweighted shaft to keep a mast always in the vertical, therefore most visible, orientation. Team 2 also uses a counterweighted mast, but chose a more upright orientation for the base of the marker. Team 3's alpha prototype utilizes six motor actuated legs to orient the marker in a vertical position after deployment for optimum visibility. By viewing the alpha prototypes, it can be seen that the PACDFA method enhanced design creativity and led the three design teams to unique designs that accomplish identical functionality. Although different in overall design and appearance, the smart marker alpha prototypes do exhibit some similarity in the mast interface and flag interface modules.

Figure 4. Smart Marker alpha prototypes.

By viewing the alpha prototypes in Figure 4 it can be seen that each team embodied the 11 modules in a variety of ways. Figure 5 shows two modules from Team 1's alpha prototype. Within these modules, minimum part count and component reuse were important design criteria. In Figure 5(a), the two cylindrical base housings represent the Delivery Tube Interface Module and the Surface Interface Module. These two casings embody six sub-functions from the marker's functional model. On the same alpha prototype, the Flag Interface Module is embodied by the clip shown in Figure 5(b).

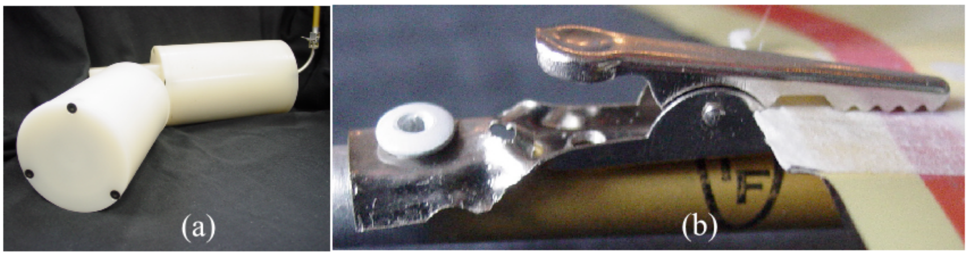


Figure 5. Module embodiment on Team 1's alpha prototype.

4. Results

After presenting the three alpha prototypes to the Army for review and critiquing, each team fabricated their beta prototypes. Each beta prototype is very similar to its associated alpha prototype but the designs have been refined to increase their functionality in this, the final prototyping stage. The alpha prototypes afforded each team the opportunity to see their design modules interact with each other in a rather crude manner. In developing the beta prototypes, it was necessary that each team improve upon the modular interactions within their designs. The beta prototypes were fabricated from actual materials of manufacture, if possible, and were intended to be fully functioning smart marking devices that the Army could rigorously test and examine.

Figure 6. Smart Marker beta prototypes.

Each team's beta prototype can be seen in Figure 6. These beta prototypes are very similar in design to their associated alpha prototypes. All modular concept variants were retained in going from alpha to beta prototypes, minor improvements and revisions however, were made. The eleven modules found through the product architecture methodology can be easily identified in the beta prototypes. In the beta prototypes, the mast interface module is the only module that exhibits a high amount of similarity between the different mechanical beta prototypes. In this module, each beta prototype uses a hinged mast that is actuated by releasing a spring. However, the method of actuation is quite different for each beta prototype. Figure 7 shows all eleven modules within Team 1's beta prototype.

The Army received these beta prototypes approximately seven months after the inception of the design project. The Army was satisfied that their requirements for the project had been met, and spent three months testing the three beta prototypes at Fort Leonard Wood in St. Robert, Missouri. Their testing included dynamic field-testing and software/electronic reliability testing.

5. Conclusions

The product architecture-based conceptual design for assembly (PACDFA) method used during the intelligent hazard marking device design project led three interdisciplinary student design teams to develop three functionally similar products with unique designs. By using the product architecture method in conceptual design, creativity in design was enhanced, product modularity was addressed and project goals were ultimately met. Also, by using this method, the smart marker project was successfully completed in a minimum amount of time while yielding three functional prototypes to the customer for evaluation.

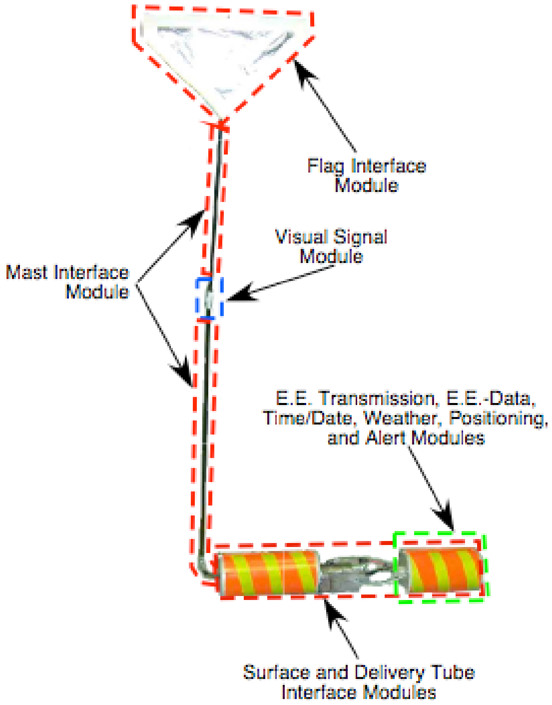


Figure 7. Team 1 beta prototype with module labels.

The product architecture method gave the design teams a methodology to define modules in conceptual design. In this design project, each design team started with the same functionality and even the same modular definitions, but all teams arrived at very disparate final designs. By examining modular product architectures in conceptual design, each team was able to develop creative modular solutions to solve the overall design problem while addressing DFA concepts throughout the design without the need to time-consuming redesigns. The overall design similarity between each team's alpha and beta prototype highlight the fact that very little redesign was necessary in arriving at a modular product design.

The PACDFA method allowed the design teams to identify a modular architecture early in conceptual design. By doing so, the teams were able to easily integrate modularity into their designs without the need for time-consuming redesigns and component modifications. The integration of product modularity in the early stages of design allowed for a seamless transition from the drawing board to physical modeling and prototyping and for assembly concerns (such as part count) to be considered throughout the process.

Customer satisfaction with the smart marker beta prototypes was high. The Army conducted a meticulous regimen of testing and evaluation on the beta prototypes to find the strengths and weaknesses of each design. The Army is developing a cumulative design for a new hazard marking system that embodies strong aspects from each of the beta prototypes.

Finally, the PACDFA methodology allowed each of the design teams to complete a large amount of design analysis and testing in a relatively short amount of time. By identifying product modules early in the design phase, modular designs could be determined in conceptual design, thus multiple redesigns were unnecessary in arriving at design prototypes that were easy to manufacture and assemble. The modular architecture of the smart markers also gave the teams an easy way to separate the necessary tasks in the design of their new marking system.

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