Modular System Build Methodology for Electro-mechanical Products

The University of Michigan-Dearborn
Henry W. Patton Center for Engineering
Education and Practice

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Annual Progress Report

Modular System Build Methodology for Electro-mechanical Products

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Synopsis

To meet their unique requirements, customers in the marketplace continue to demand low-cost, high-quality products with special features delivered sooner than ever. The challenge to industry is to economically create the desired product variety to meet varied customer requirements. Modularization is an approach which breaks product structure into smaller, more manageable units and makes customization possible and economical. Modular design is a form of standardization in which component parts in a system are subdivided into modules that are easily replaced or interchanged. By separating the parts of a design that should vary from those that should be kept as common units, system variety can be accommodated, and complexity can be kept manageable. Thus, a total redesign of the product is no longer needed every time a new system variant is introduced. In general, the use of modular product design allows for 1) a higher number of customer-requested variants and customization possibilities; 2) easier diagnosis and remedy of failures; 3) easier repair and replacement; 4) simplification of manufacturing and assembly; and 5) potentially fewer parts to deal with, purchase, and inventory.

In this research we propose to develop modular system build methodology and product design evaluation techniques that will allow companies to develop alternative product design concepts using the modular design approach, and evaluate these candidate concepts in the selection of the final design for product launch. The goal of the project is to document and illustrate the benefits of modular design.

If successful, our proposed methodology will allow our industrial partners to 1) develop modular product architectures to economically meet varying customer requirements; 2) identify common modules and architectures which can be shared across multiple product platforms; and 3) manipulate and evaluate alternative product designs using competing objectives. In addition, models, algorithms, and documented case studies developed in this research will be presented and discussed in several Industrial and Manufacturing Systems Engineering (IMSE) and Engineering Management (EM) courses at the University of Michigan-Dearborn.

1. Background

To meet their unique requirements, customers in the marketplace continue to demand low-cost, high-quality products with special features delivered sooner than ever. The challenge to industry is to economically create the desired product variety to meet varied customer requirements. Modularization is an approach which breaks product structure into smaller, more manageable units and makes customization possible and economical. Modular design is a form of standardization in which component parts in a system are subdivided into modules that are easily replaced or interchanged. By separating the parts of a design that should vary from those that should be kept as common units, system variety can be accommodated, and complexity can be kept manageable. Thus, a total redesign of the product is no longer needed every time a new system variant is introduced. In general, the use of modular product design allows for 1) a higher number of customer-requested variants and customization possibilities; 2) easier diagnosis and remedy of failures; 3) easier repair and replacement; 4) simplification of manufacturing and assembly; and 5) potentially fewer parts to deal with, purchase, and inventory.

In this research we propose to develop modular system build methodology and product design evaluation techniques that will allow companies to develop alternative product design concepts using the modular design approach, and evaluate these candidate concepts in the selection of the final design for product launch. The goal of the project is to document and illustrate the benefits of modular design.

The long-term research interests of the principal investigators (PIs) involved in this research is in product development and evaluation. Each of the PIs has unique expertise and experience in various areas of product design and development that will contribute to the success of the proposed research project. The proposed research also provides a unique opportunity for the PIs to collaborate in this field.

2. Objectives

We propose to develop modular system build methodology that combines product requirements modeling, modular design concepts, and product evaluation and optimization techniques which allows our industrial partners to:

- Develop modular product architectures to economically meet varying customer requirements;
- Identify common modules and architectures which can be shared across multiple product platforms;
- Manipulate and evaluate alternative product designs using competing objectives;
- Document and illustrate the benefits of modular design; and
- Enhance a heightened awareness of engineering design as an important element of engineering education and practice.

3. Approach

This section outlines the tasks of the proposed modular design approach with some brief explanations.

Task 1: Develop requirements-driven system model and perform functional decomposition.

Develop a requirements model for electro-mechanical products and perform functional decomposition by breaking down the overall features/functions of a product/system into smaller, easily solvable sub-functions. The decomposed model will spell out in detail what the product has to do to meet customer requirements, clearly identify interfaces between the functional elements, and flow down requirements and their take-rates into functional elements. Feature/function take-rates represent the percentage of the products that are equipped with the feature/function.

In essence, the requirements model is a large directed graph that captures the relationships (i.e., information, energy and material flow) between the functions of electro-mechanical products. Once the system requirements model is developed and functional elements and their relationships are obtained, the incidence matrix for the system functions can be constructed and clustering techniques can be used to group the functions and create modules (see Task 3).

Task 2: Identify design constraints.

Identify key constraints in establishing modules, such as features that need to be self-contained, features that must be tested independently of other features, features that need to have unobstructed access, features that need to be totally interchangeable, and so on.

Task 3: Cluster functional elements and build modular product architectures.

Develop and apply clustering techniques to identify potential functional/physical modules and their interfaces. Examine and modify the modules if necessary to meet all the corporate, supplier, design, constraint, and product performance requirements. In this step, several different modular design alternatives and criteria (packaging, complexity, manufacturability and retirement cost) to judge the alternatives will be developed that will allow one to determine which alternative better fits the needs of the company. To accomplish this task, new clustering and optimization algorithms as well as product evaluation techniques will be developed.

Three different modular design approaches will be investigated:

1) take-rate approach – modules are developed so that functions with similar take-rates are confined to the same module;

2) coupling and cohesion approach – modules are developed so that interdependence (coupling) between two design modules is minimized and relatedness of the components of a design module (cohesion) is maximized; and

3) hybrid approach – modular design which provides the best possible tradeoff between the design objectives outlined in (1) and (2) above.

Task 4: Create a modular system schematic. Develop module and interface specifications.

Develop a three-dimensional schematic to show how modular components interact and how each modular component interfaces with other modular components. Examine and modify the modules if necessary to meet all the corporate, supplier, design, constraint, and product performance requirements. Ensure all desirable criteria have been met. Draw up detailed specifications for each module and interface.

Task 5: Develop case studies. Validate and document benefits of modular systems.

Apply the methods and algorithms developed in this research for the design and development of the electro-mechanical systems provided by the industrial partners. Demonstrate on these specific design examples how a product can be modified for future designs, and document the benefits of modular systems.

4. Results

The results of this project are new models and algorithms for modular product/system development that will allow our industrial partners to develop modular product architectures to economically meet varying customer requirements, identify common modules and architectures that can be shared across multiple product platforms, manipulate and evaluate alternative product deigns using competing objectives, and document and illustrate the benefits of modular design.

5. Conclusions

The challenge in industry is to economically create product variety in order to meet varied customer requirements. Modularization is an approach to break product structure into smaller, more manageable units and make customization possible and economical. Modular design is a form of standardization in which component parts in a system are subdivided into modules that are easily replaced or interchanged. Modular design methodology developed in this research can facilitate quick and effective alternative product concept development and evaluation, and help to reduce product development time and cost. The models and algorithms developed in this research will also help design engineers to better understand design trade-offs at the early stages of concept development by manipulating design concepts and evaluating their impact on design objectives.

6. Impact

Educational:

Models, algorithms, and documented case studies developed in this research will be presented and discussed in several Industrial and Manufacturing Systems Engineering (IMSE) and Engineering Management (EM) courses. For example, new modular design build methodology, clustering algorithms and matrix decomposition approaches developed in this project will be covered in the courses EM 580 Product Design and Development and IMSE 583 Design for Manufacturing and Assembly. Students in these classes will be assigned product design problems, asked to use modular design build methodology to develop alternative design concepts, and discuss their advantages and disadvantages.

Industrial:

The proposed research in this project is directly related to the needs of industry. The models, algorithms, and software developed in this research attempt to extend the current state of knowledge in product design and development to solve problems that are directly related to the competitiveness and needs of national manufacturing industries. A short and predictable product design cycle is critical to the success of companies in the era of time-based competition. Tools and algorithms that can facilitate quick and effective alternative product concept development and evaluation may have a significant impact on product development time and cost. The models and algorithms developed in this research will reduce product time to market, and help design engineers better understand design trade-offs at the early stages of concept development by manipulating the design concepts and evaluating their impact on design objectives.

7. Acknowledgments

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