The XXVIIIth Annual Occupational Ergonomics and Safety Conference
Chicago, Illinois, USA
June 9-10, 2016

A Design for 'X' Methodology Based On Modular Design Techniques

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Abstract: Every year, the market is awash with new products and technologies. However, a very small percentage of such product introductions are successful. The ultimate success of a product is a function of several variables such as economic and cultural factors and pre-existing competition. However, it can be shown that a well-researched and efficient design distinguishes successful products from also-rans. Product design and development is a thoroughly researched topic. Most of the underlying research on product development is based on the 'Design for X' (DFX) philosophy. In spite of such active research on the topic, there is no framework for product design and development that can serve as a roadmap to enable the designer through each design criterion, in the DFX methodology. If such a framework existed, it would list the design attributes and factors for each of the design criteria. This paper seeks to establish and present a framework for designing products, primarily product modules in order to enable ease of assembly, disassembly and reproducibility. The framework relies on interactive decision making. Its principal aim is to guide designers through each factor that may be critical in the particular design. The framework described here considers eight different design criteria. Each design criterion is broken into design factors and sub-factors. Design modules are developed on each criterion and are discussed separately. The design factors within each module are also discussed and their influences are addressed at length.

Keywords: Design, Functionality, Assembly, Disassembly, Cost, Module

1. Introduction

Product development is the process by which new products are designed and developed. New products bring new economic and business opportunities to companies marketing them. But, they carry an inherent risk of failure. Studies of new product failure rate have stated that out of 3000 raw ideas, 100 exploratory projects are undertaken. Of these, 10 well-developed projects materialize and 2 fully fledged products are launched; only one attains commercial success. These statistics have remained unchanged over the past 40 years (Stevens and Burley 1997).

A systematic approach to product design begins with conceptualization of an idea by designers and its evaluation in terms of risks of failure, economic impact (profitability), and social impact (acceptance). Design refers to the activities that deal with the physical entities such as color, style, appearance, material, function, and feel of a product whereas development includes market research, identification of an opportunity to introduce a new product that appeals to the market, testing, evaluation, modification after the initial design process, and finally marketing of the product during and after the design process and the final launch (Morris 2009). It may be undertaken by an individual, an enterprise or a business. Although the broad prospect of design and development is the same for all products, the methods and their implementation vary greatly from one product to another.

The present day design engineering process is focused on the Design for Excellence or Design for 'X' (DFX) methodology. In this methodology, X stands for various design criteria such as 'Functionality', 'Assembly and Disassembly', 'Usability', 'Reliability', 'Materials', 'Quality', etc. The intended objective of this methodology is the incorporation of elements from all these design considerations concurrently such that their interdependence is well defined and within the acceptable limits that will not hinder the overall success of the product (Ullman 1992, Chu and Holm 1994, Bralla 1996, Huang 1996, Gupta et al. 1997, Mak and Huang 1998). It is desirable to integrate multiple design criteria in order to eliminate any conflict.

This paper aims to develop a framework for product design by establishing inter-functional dependence of the design elements for each criterion of product design for engineered products. It should be noted that the incorporation of multiple design criteria does not mean the optimization of any element with respect to any one criterion, but selection of the best possible compromise that is within the acceptable limits for all the discussed design elements pertaining to each 'X'. The paper seeks to present a concept, it is not a methodology. The overall framework of the concept has been presented. This framework can be developed into a methodology in the future and as such could be the topic of future research and publications emanating from that work.

2. Methodology

In the DFX paradigm, ‘X’ stands for different design criteria or goals, such as functionality, quality, reliability, etc. The proposed framework is divided into separate modules, each corresponding to a particular ‘X’ in the DFX methodology. These modules are further broken down into a list of design factors and their attributes and features (quantitative or descriptive or both) are identified. These design factors are used to collect design specific information from both designer interaction and the actual CAD model. The list of design factors is not exhaustive and each module has provisions to expand this list and add more design factors based on specific requirements. Details regarding design factors corresponding to each module are discussed at length in latter sections of the paper.

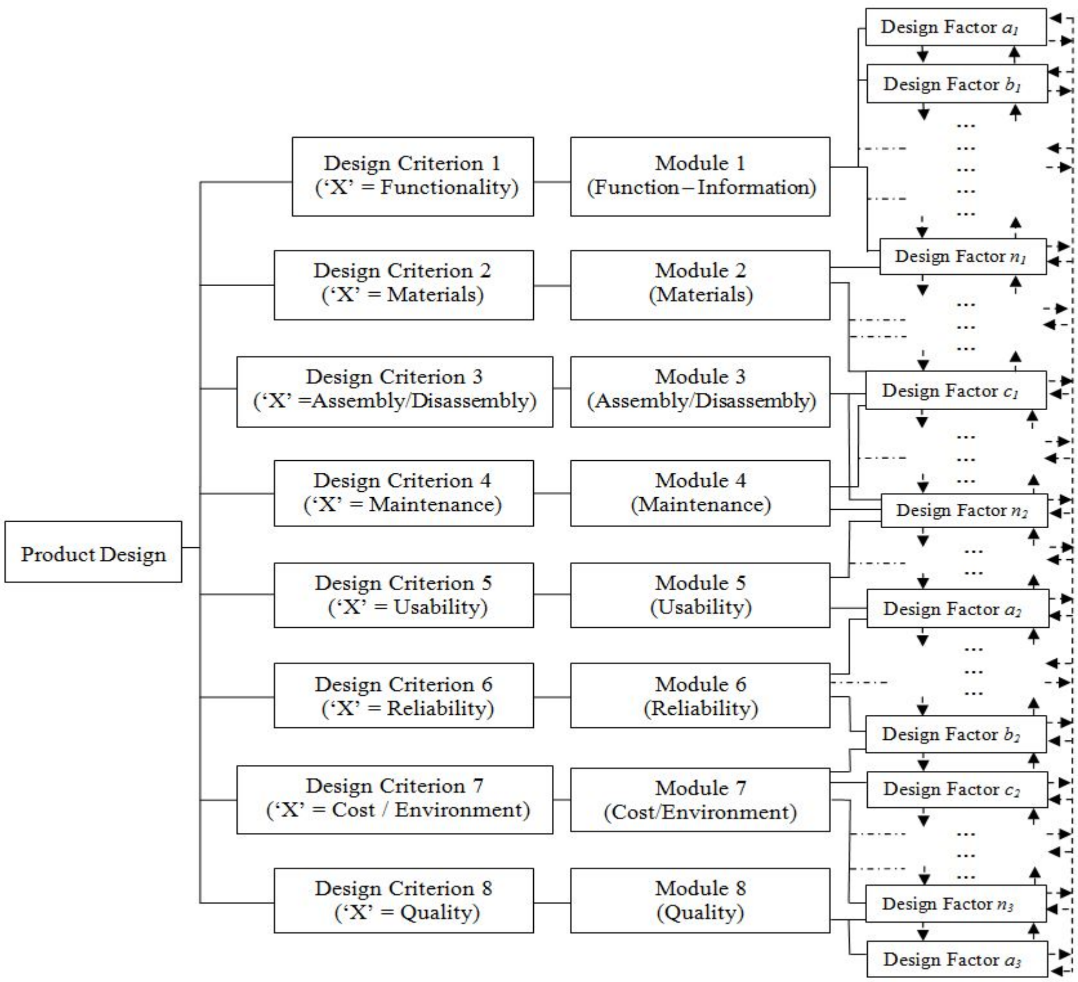

Figure 1. Methodology for establishment of the framework and interaction between criteria, modules and design factors. Same design factors may be part of different modules

Figure 2 shows the modules that are considered in the framework. These modules are: Functionality, Assembly/Disassembly/Maintenance, Usability, Material Selection, Reliability, Quality, Cost, and the Environment.

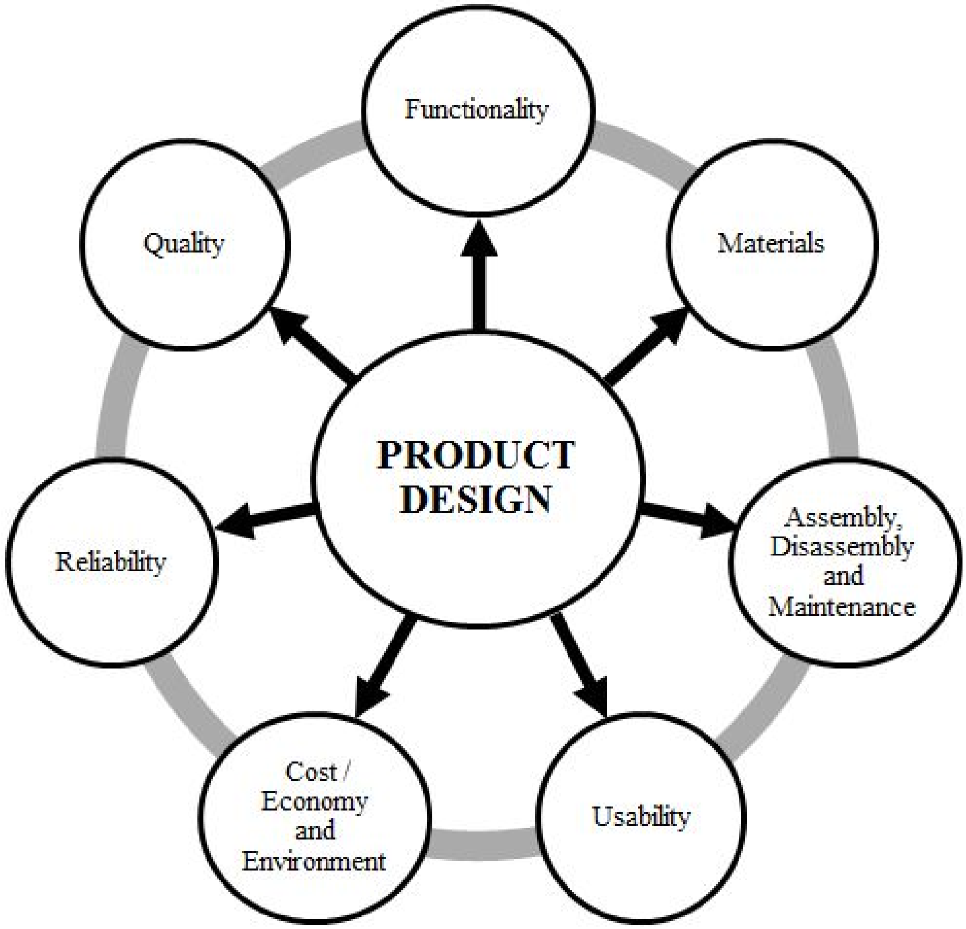

Figure 2: Modules in the framework for product design

Function is the most important aspect of any design. All product designs exist to satisfy some function. Products that do not provide the intended function are set to be a certain failure. 'Design for Functionality' of a product ensures the final design fulfills the basic needs/functions that led to the initial conceptualization of the product. Function is an abstract concept that depends on a number of varied and complex factors. Even though functionality is a well-researched area in the field of product design, it has no clear or uniformly accepted definition. Several research techniques have been established in the past to represent function in an organized way that can be applied widely to a variety of products. Some of the successful ones include, Value Engineering System (Miles 1972), Function Analysis System Technique – FAST (Bytheway 1971), Rodenacker's Methodology for Functional Representation (Rodenacker 1991), and Sturges's Extended Function Logic (Sturges et al. 1996). The general objective is to develop a methodology to represent functions irrespective of the nature of the product and assist design from a functional point of view.

Material selection plays a major role in realizing the functional aspects of a product. A good material must provide optimum properties required by the product, economically. Costs associated with material selection include not just the cost of material, but the cost of its availability, manufacturability, maintainability, serviceability, usability, disposability, and environment compatibility. The concept of 'Design for Material' aims at improving the design to take complete advantage of all the features of material discussed above.

Most products today are made of multiple components or parts. For example, a standard bike is made up of more than 200 parts, an automobile of nearly 30,000, and a Boeing 747 aircraft in excess of 6 million. If individual components are not designed for the ease of assembly, manufacturing and assembly become an expensive and time consuming process. The same factors apply to disassembly and maintenance when disposal, recycling, and repairs are taken into account. Hence design for assembly (DFA), design for disassembly (DFDA), and design for maintainability (DFM) are important aspects of product design.Assembly and disassembly being reverse operations in nature; the design factors for both operations have been identified and classified into the same category to ensure uniformity of information in the design process. The determinants in an assembly/disassembly procedure can be divided into three sections: ends, means, and processes.

The design factors for assembly and disassembly are categorized into four attributes: grasping, motion, orientation, and connection. These are introduced to categorize design factors in the assembly/disassembly module under each specific and progressive stage of product development from the initial physical factors that influence the basic features of the product, such as strength and reliability, to the finished product that has to be assembled or disassembled.

Maintenance tasks can be divided into two categories: preventive/predictive maintenance and corrective maintenance. The repair, or restore, activities that are undertaken after a specific amount of time, or equipment use, are termed as preventive/predictive maintenance. The repair or restore operations that are undertaken after a specific amount of time or equipment use is termed as corrective maintenance. Due to the nature of preventive or predictive maintenance, where routine maintenance activities are conducted with the whole equipment failure in mind rather than a localized issue, the design factors listed in this module are more applicable to corrective maintenance. The three determinants to classify the design factors affecting maintenance operations have been derived from the Federal Electric Method (Harring et al. 1965). These determinants are termed as pre-maintenance, in-maintenance, and post-maintenance operations. The classification of design factors that are applicable to all the determinants has been derived from functionality and assembly/disassembly sections.

The ISO 9241-11 Guidance on Usability (Standardization 1998) defines usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use”. In every successful product, there is a high degree of user interaction which may be physical, cognitive or both. It is important to have a simple yet appealing usability interface between the consumer and the product. Different products that are conceptualized with the same functionality in mind will not be equally successful and this can be attributed to the usability, reliability, and cost features of the products. Also, a technologically sophisticated product with complex usability features may not appeal to the masses as its counterpart which may be less advanced technically and yet more user-friendly. Hence, usability of a product is an important criterion in product design. The design factors to ensure usability of a product can be categorized into five determinants: user, functionality, reliability, safety, and maintainability. The user aggregation level comprises of design factors that make a product more attractive from users’ point of view. These can be further divided into safety features, human factors, aesthetic features, reliability features, and maintainability features. Aesthetic features can be further divided into product specific features, shape features, and surface features. The functionality aggregation level classifies the functionality design factors that affect the usability of the product. These factors include the shape, performance, and force-motion factors mentioned in the Function-Information module. The reliability aggregation level refers to the design features and factors of a product that ensure its usability and functionality. The design factors in this level can be derived from the material properties (Material Module), functionality requirements (Function-Information Module), and the human factors. The level of maintainability of a product affects its usability, functionality, and reliability. The usability and functionality of a product declines over time and it is essential from the stand point of product success that a high level of maintainability exist to restore the usability of the product or the component. The absence of undesirable events during the life cycle and operation of a product is termed as safety. This is an important criterion in product design as the demand for a product that has been deemed unsafe will decline and product recall is a very expensive and time consuming process. Further, it damages the reputation of the manufacturer. The major areas that affect product safety include material properties (Material Module), human factors (Assembly-Disassembly module), forces on the products, motion of the components (Function-Information Module), etc.

Reliability can be described as the probability that a product will satisfactorily perform its intended function under certain operation conditions for specified operating conditions. Product reliability is an important phase of design as poor reliability results in frequent product failure, greater repairing and warranty costs, customer dissatisfaction, sales, and overall business failure. The factors that facilitate the need for product reliability are product complexity, user specified clauses, market competition, designer or company reputation, cost effectiveness, and history of system failures. These factors in turn lead to the different stages of design for reliability, such as definition of the failure criterion, identification of the acceptable limits, analyzing the past system failures, quantification and improvement of the reliability factor within the acceptable limits, validation of the reliability factor of the product and monitoring, and control of this factor. The reliability module in the framework consists of design factors categorized into 5 aggregation levels: mechanical aggregation level, human aggregation level, maintainability aggregation level, environmental aggregation level, and contributory aggregation level.

In the design for cost and environment module, the aggregation levels associated with the developmental costs and environmental impacts on product design are discussed in two separate sections. Product Design has a large influence on manufacturing cost. To keep the selling price competitive, it is necessary to reduce the manufacturing cost to the lowest possible level. Studies have indicated that early stage of design can account for 70 % of the total cost associated with a product, while the actual design process accounts for only 6 % (Pham and Ji 1999). Hence the cost related decisions during the design have a much significant impact than the actual manufacturing cost of the product. This showcases the importance of designing for cost effectiveness in the product design framework. The cost/economy module in the framework categorizes the generic costs inquired during a design phase. The aggregation levels for the cost/economy module can be broadly termed into four categories: form costs, material costs, process costs, and assembly costs. Form cost aggregation level is associated with the costs that are required for the products or components to attain the form features such as shape, size, other geometrical features, accuracy, and surface features. The form cost is a precedent in determining the material cost and the process cost as it can suggest the viable options in these two aggregation levels. Material selection is a complicated process that has to be made early in the design process. The many constraints to material selection would be the forms and features, functionality, process capability, and the associated costs. Once the material selection is done, these constrains again apply to the processes that can be applied in their realization. The factors that affect material and process costs are form and function of the product, material properties, and the associated costs with the process that is required to attain the forms and functions, of the product. Assembly costs include the connection costs, labor cost, and tool cost. The selection of fasteners and tools are dependent on the form and material of the product and its components. The operator costs depend on the human factors and the assembly module described earlier in the framework. End–of–life (EOL) concerns exist in every product design and development process. Consumer demands, competition, and legislations are major factors that incorporate the need for design for environment. Design for Environment includes different product development activities, such as appropriate material selection, usability analysis for environmental friendliness, designing for energy efficiency, adoption of environmental friendly manufacturing methods, designing for end-of-life, improvement in packaging, and removal of toxic materials during manufacturing purposes.

3. Conclusion

This work is the first step towards developing a comprehensive interactive system to guide designers to improve their design based on the DFX methodology. The framework of an interactive modular system was explained with an emphasis on important design factors necessary for establishing the modules. Figure 3 represents the different modules, aggregation levels and pertinent design factors.

For a system to guide the designer, it needs design specific information. Since the system will operate as an extension to an existing CAD package, part of the information can be extracted directly from the CAD model. However, important design factors such as operating temperature of the product, or geographic location of manufacturing plant, are only accessible through the designer. The system interacts with the designer through an interactive questionnaire to obtain this information. The next step involves developing the logic behind each of the modules and understanding the correlation between them. Each module must be an interactive functioning unit with the capacity to store information based on the designer's CAD model and designer interaction, use them as a data handle to correlate design rules and recommendations from a central database, and suggest design modifications and improvements to the designer.

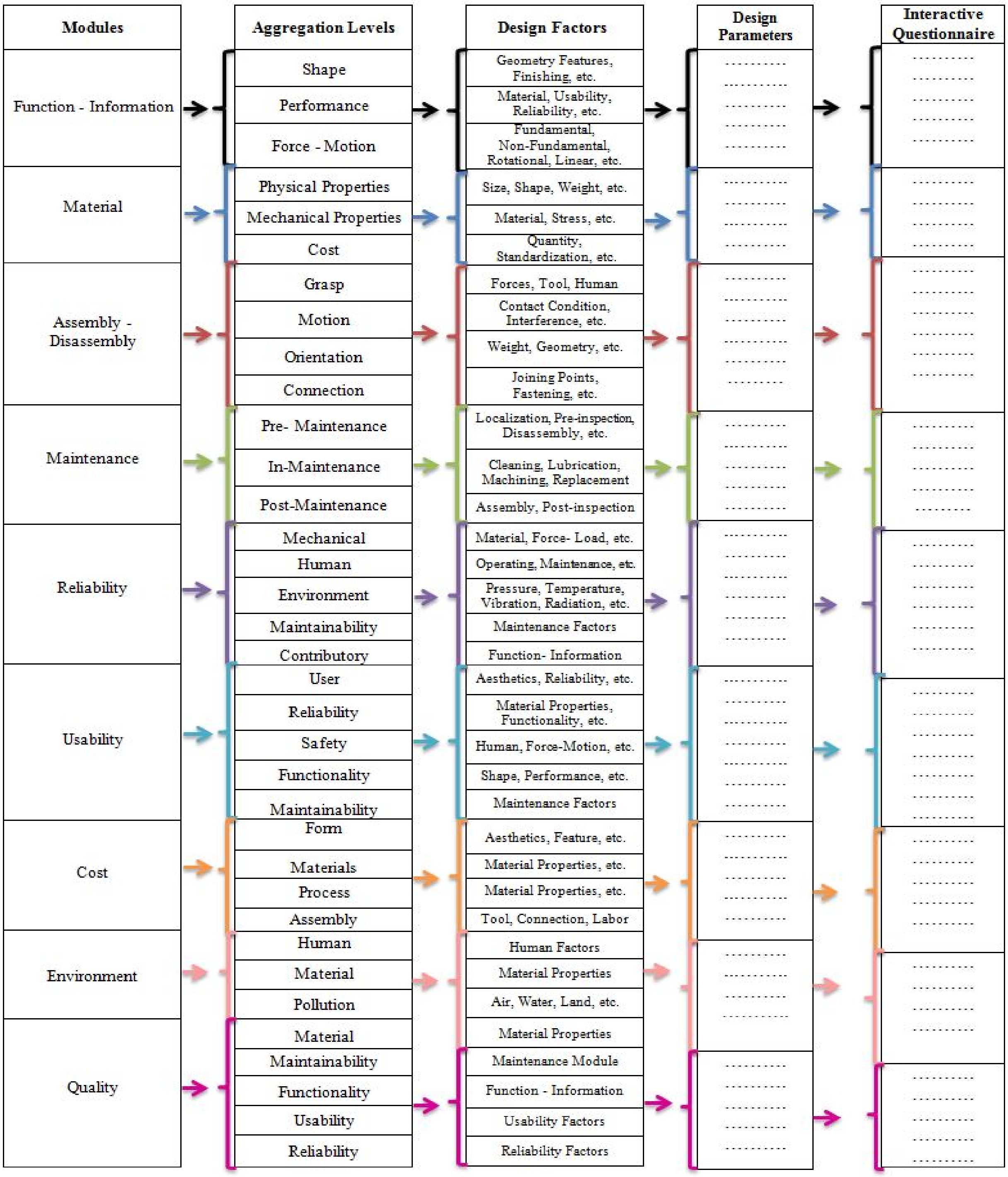

Figure 3. Different design modules, aggregation levels and design factors.

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