SPIECIES: STEPWISE PROCEDURE FOR INCORPORATING ENVIRONMENTAL CONSIDERATION INTO ENGINEERING SOLUTIONS

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ABSTRACT. Concerns about exploitation and deterioration of natural resources and emergence of unprecedented social problems have created a need for reevaluating the way engineered products are designed and how they impact the environmental systems. Concurrent design methodology is an interdisciplinary approach that simultaneously takes into account technological feasibility, economic profitability, environmental sustainability and societal values for finding optimal design solutions. The objective of this work is to develop a methodology by which designers can identify, quantify and integrate environmental and societal considerations in their design solutions.

INTRODUCTION

The last decade has witnessed the need for more environmentally conscious products and systems. As a result, methodologies such as Green Design, Design for Environment and Deep Design are becoming common design tools used by the engineer. Most of these methods help the engineer to define ways to increase material efficiency, enhance recycling and use environmentally friendly manufacturing techniques such as lathing with biodegradable machining oils. However, the engineer applies these methods toward the end phase[1] of product development (e.g., product manufacturing) rather than during the initial planning phase of design. As a consequence, many important qualities of natural systems are often not considered. Thus, many engineered products and systems fall short of society's demands for the environment, and many design solutions considered environmentally sound by the engineer are frowned upon.

Engineers are often times accused of being unable and reluctant to integrate many environmental issues into their designed products, however few design techniques are available for transforming the 'soft' and qualitative issues of ecology, social psychology and ethics into the quantifiable terms. The objectivity of engineering as well as other physical sciences is considered by many environmentalists to not be compatible with the qualitative environmental desires of society. Engineers have trouble quantitatively defining issues such as beauty, livability, and ecological integrity and then integrating these factors into their designs. The objective of our recent activities has been to develop a methodology, SPIECES that makes seemingly nebulous concepts compatible with engineering objectivity. SPIECES places environmental and social issues in the problem definition phase of design when the constraints of a product are being developed. SPIECES also provides logical steps for defining abstract issues (e.g., beauty, livability, and ecological integrity).

WHAT IS SPIECES?

SPIECES is a step-wise procedure that follows the principles of Quality Function Deployment (QFD) and uses multivariable analysis methods. The SPIECES relationship matrix (Figure 1) provides a visual tool that allows the engineer to separate issues and rank them in order of importance. This relation matrix is completed during the problem definition phase of design and therefore, makes environmental and social constraints equal to traditional engineering constraints (e.g., assemble time, cost, the strength of a reinforcing rod) at the beginning of the design.

Somewhat different to QFD, SPIECES is also applied during the concept develop phase of design and allows objective evaluation of conceptual solutions. An Efficiency Score (Esteghlalian *et al*, 1997) can be assigned to each concept where the higher the score the more environmentally friendly and socially acceptable the concept. However, the accuracy of the scoring scheme is highly dependent on the reliability of the gathered information. Care must be taken not to choose just the concept with the highest Efficiency Score. Rather, the score

1 Design Phases: Establishing a need, Planning, Problem definition, Generating Conceptual Solutions, Conceptual selection, Detailed design, production

Engineering

Customer

Customer	Importance Rating	Number. of animal	No. of plant species	No of aquatic species	No. of food chains	Density of tall trees	Density of shrubs
Preserves complexity/ diversity of ecosystem	13	9	9	9	9	3	3
Maintains integrity of the local ecosystem	15	9	9	9	9	9	9
Uses renewable material and energy resources	4	1	1	1	1	1	1
Preserves peace/ serenity of environment	6	9	9	9	9	3	3
Does not harm the sense of freedom and limitness	10	3	3	3	3	9	3
Creates awareness and appreciation of nature	8	3	3	3	1	3	3
Current Value							
Design Value							
Remediation Value							
Restoration Value							

Figure 1. Abbreviated version of a SPIECES relationship matrix.

should be used to group concepts thereby focusing decisions.

HOW TO USE SPIECES

The first activity of SPIECES is to list all human and non-human entities affected by the design (e.g., wetlands, rural communities, and small neighborhoods). The next activity is to determine the important environmental and social constraints that each of these entities place on the design solution. Typically, these constraints are expressed in qualitative terms. For example, a group of homeowners may wish for a forest operation to not disturb the beauty of a hillside. As with QFD, these qualitative constraints must be decomposed into their most elementary underpinning. For example, the *beauty of a hillside* may be decomposed into *steepness of the slope, the ratio of vegetated area to bare area, number of visible colors, the number of tall trees*, just to name a few. Decomposition of a constraint is halted when each underpinning is considered measurable. These measurable underpinnings now become the constraints that guide the engineer during the remainder of the design process and are used to make logical design decisions.

Once all attributes are decomposed, the relation matrix is developed (Figure 1). In this matrix, the qualitative constraints (customer wants and needs) are placed on the left as rows. The first column of the matrix is the importance of each of these constraints as defined by the affected entities. This involves interviews, reading of literature and similar activities. In Figure 1, the important rating is expressed as a percentage of importance. The underpinnings (engineering requirements) are placed across the top as the other columns. As shown, a single underpinning may be shared by several qualitative constraints. A 1-3-9 scoring system is used to indicate relationship strength between the *customer wants and needs* and *the engineering requirements*. A one (1) indicates a weak relationship while a 9 indicates a strong relationship. Once the matrix is complete, the arrangement of these three numbers can be used to identify design trends and help guide design decisions.

After the relationship matrix is completed, it is time for the SPIECES user to assign numbers to the engineering constraints. This is done by determining current conditions and design impact conditions. Current conditions reflect how the environment would exist without the design (e.g., the number of tall trees before the forest operation). The design impact condition reflects how the environment is going to change due to the design. Subtracting current conditions from design impact conditions will help the engineer to determine the effects of each different conceptual design solutions. Two other conditions, restoration and remediation, are also considered in a similar manner. Summation and normalization of these calculations produce the Efficiency Score thereby giving a single condition score instead of several condition scores which can be too numerous and overwhelming. Exact application of the SPIECES procedures can be found Esteghlalian *et al.* (1997).

FIELD TESTING OF SPIECES

During 1998, SPIECES was used by a group of University of Georgia engineering undergraduates who were designing a university recreational park. This exercise provided our research team with a controlled situation where we could study the ability of inexperienced engineers to follow SPIECES procedures. Results indicate that the methodology is easy to follow and helps the inexperienced engineer to formulate decisions faster and to develop more environmentally friendly concepts. During the spring of 1999, SPIECES will be applied at the field level. Our research team will assist staff of Clarke County's Sandy Creek Park to develop a 20-year master plan for the park.

REFERENCES

Esteghlalian, Alireza, Brahm Verma, T. Foutz, S. Thompson. 1997. Incorporation of environmental and societal considerations into engineering design. Proceedings of IDEA '97: Intelligent Design In Engineering Applications. Aachen, Germany, September 11, 1997.