Development Concurrent Engineering : Product Design Evaluation

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ABSTRACT

The design development, and production of a product is one of the greatest challenges which flexible manufacturing systems face today. No matter how a company refines and controls the manufacturing process, if the product is not properly designed, it will not operate correctly or performed well. Therefore the focus on quality of design must be balanced.

One such strategy certain to address the managerial and manufacturing of the future is concurrent engineering. Concurrent engineering calls for the consideration and inclusion of product design attributes satisfying all the design constraints such as customer requirements.

Furthermore, concurrent engineering has been recently promoted in many industries as a response to competitive marketing pressures. Viewed as a systematic approach of creating high quality products and bringing them to market at lower cost and in significantly less time, it also attracts the attention of quality designers.

In this paper, a methodology and model for optimizing the product design, especially selection of optimal design alternative, is developed. The focus of this paper is on product design as the most critical activity of concurrent engineering.

The model is based on the customer requirements for quality. Customer requirements for a certain product can be grouped based on the various design attributes. The design attributes have the priorities. The number of design specifications can be determined based on the design functions. Design attributes value are calculated, however these values are applied to the optimization method. Numerical example will be illustrated.

1. Introduction

There are various approaches to concurrent engineering as follows:

a. Organizational and cultural changes
b. Information systems, software design, and artificial intelligence
c. Computer aided design and computer aided manufacturing integration
d. Life cycle costing or unified life cycle engineering
e. Design for assembly

However, it is difficult to perceive that the full benefits of one approach can be realized without the impact and ramifications of other approaches considered concurrently. A review of published literature in the application of concurrent engineering to modeling of the product design provides an inadequate amount of information. The lack of a formal theory of design and universal design principles has caused major difficulties in product design (Dixon 1989). He argues that until a design theory is developed, there exists a lack of consensus and variations in approaches to product design among researchers. Another major difficulty seems to be inconsistent use of terminology or definitions of various design concepts among design literature. This has particularly contributed to confusion in communication and had made the design literature susceptible to varying interpretations.

Literature review can be divided into following six categories:

a. Phase of product design
b. Concurrent engineering
c. Design school
d. Optimization of decomposed systems
e. Multiattribute decision making
f. Mathematical programming techniques

2. Optimization Modeling of Product Design

Most of product design is based on the customer requirements (C_i). The typical design attributes (a_j) considering in mechanical design are shown in Table 1. The weighted matrix between a_j and C_i is formed. The unrelated relationship between a_j and C_i reduces the number of feasible a_j and C_i by network decomposition method. Then all the weights of given a_j are determined and normalized. Those normalized weights of a_j used to optimization modeling.

Attribute	Factors
Durability	abuse, misuse, accident, corrosion, humidity., strength, moisture
Performance	force, velocity, acceleration, pressure, energy, handling, comfort, features
Producibility	tolerances, surface, roughness, dimensions, structure, stress level, size, geometry, height, breadth, diameter, space requirements, connection, arrangement, extension, kinematics, weight, load, deformation , stiffness, elasticity, resonance, operation
Reliability	repeatability, testability, measure of availability, duration of downtime

Safety	electrical and mechanical noise, stability, illumination, direct protection system, operational safety, environmental safety, fail sage restrictions, explosive components, magnetic field, free of sharp edges, pinch points, adequate warning mechanisms
Marketability	profit margin, marketing mix, target customers, product differentiation, product quality, price versus quantity, market share, product life cycle serviceability, easy of repair, time to service
Maintain-ability	continuous, regular, sporadic, none, painting, ease of inspection, ease of repair, availability of parts, ease of part replacement, part shelf life cycle
Schedulability	average flow time, maximum flow time, average machine idle time, maximum completion time, delivery dates, capacity, average machine utilization time Esthetics shape, size, color, texture, cosmetic, styling, social significance, mass impressions, critical dimensions, proper blending

Table 1. Design attributes and factors

Figure 1 shows the scope of concurrent engineering model. the following steps are developed to optimization modeling for design alternatives.

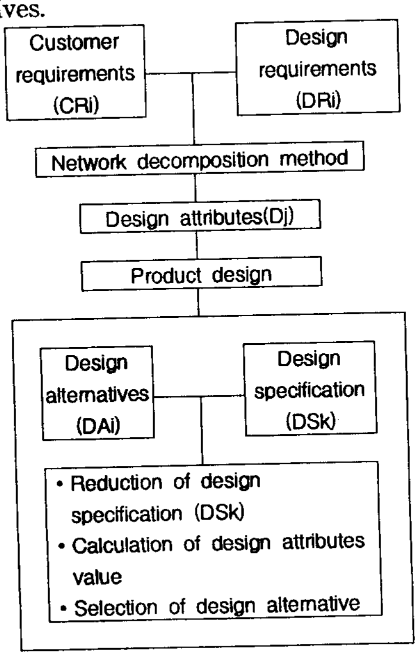

Figure 1. Scope of concurrent engineering model

Step 1. (Formation of matrix): When the customer requirements (C_i) are given, the design attributes (a_j) are assigned by relationship weights (0 to p). Then corresponding matrix can be formed as follows:

$$Matrix\ (W_{ij}) = \begin{cases} weght\ , & \text{if } \textit{there is any relationship between } a_j \text{ and } C_i \\ 0, & otherwise \end{cases}$$

where,

$$weight = \begin{cases} p, & \text{if } \textit{the relationship is very strong} \\ p-1, & \text{if } \textit{the relationship is strong} \\ p-2, & \text{if } \textit{the relationship is medium} \\ p-3 & \\ \cdot & \\ \cdot & \\ 0, & \text{if } \textit{no relationship } \exists \end{cases}$$

Step 2. (Reduction of feasible options): The network decomposition method identifies the unnecessary components (Kusiak and Cho 1991). Remove those components and rearrange matrix (W_{ij}).

Step 3. (Determination weight of a_j): Add all weight of each column (a_j), and normalize design attributes weight (W_j).

Normalized design attribute weight(w_j)

$$= \frac{\sum_{i=1}^{m} w_{ij}}{\sum_{j=1}^{n}\sum_{i=1}^{m} w_{ij}}$$

where m=total number of C_i, n=total number of a_j, $\sum_{j=1}^{n} = 1$.

These W_j are used to determine the design attribute value which is applied to optimization model.

Step 4. (Determination value of a_j): A modified and expanded version of the rating system developed by Muther (1961) is presented. The seven-level rating allows the expert to assign rates (r_j) to various combinations of design attributes among the design specifications (s_i). The highest value 7 is assigned to an absolutely superior design attributes while the lowest value 1 is assigned to a significantly inferior design attribute. the total rating values assigned to any two design attributes for each pairwise comparison must be equal to 8. One base design attribute (for example a1) is compared against all other design attributes in sequential order.

The design attribute value before normalizing process(w'_j) $= \frac{w_{jrj}}{w_{lrl}}$

Then normalized design attribute value(v_j)

$$= \frac{v'_j}{\sum_{j=1}^{n} w_{jrj}/w_{lrl}}$$

step 5. (Utility values for design alternatives): choose three design attributes with the highest normalized values v_j. Add these three values and consider it a utility value for that particular design alternative. The utility values will be applied to the optimization model.

Step 6. (Optimization modeling procedure)

A. For the efficiency of solving design problems, it is more desirable to select a design alternatives which combines all the given design specifications rather than to select designs fir each design specification. In that sense, the design alternatives

(A_j) are grouped based on the design function.

B. Fuzzy theory is used to find out the optimal design alternative. The membership function $d_j(a,b)$ is defined to give outranking degree of design alternative b by the design alternative alternative a under fuzziness regarding only the ith design specification. For a specific pair of design alternatives (a,b) and more generally for any pair, the following membership function is defined (Siskos et al. 1984). Then the partial outranking relation will be produced. When g (a) varies within the interval [$g_i(a)$, $g_i(a) + t_i$], and given the inherent fuzziness of the evaluations, a continues to be at least as good as b but its credibility is less and less great.

$$d_i(a,b)=\begin{cases}1, \text{ if } g_i(b)-g_i(a)<0\\ 0, \text{ if } g_i(b)-g_i(a)>t_i\\ \textit{between } 0 \text{ and } 1, \textit{ otherwise}\end{cases}$$

for $g_i(b)-g_i(a)\varepsilon\,|\,0, t_i\,|$ the decrease of $d_i(a,b)$ can be determined by linear interpolation or any other formula as follows:

$$d_i(a,b)=\left[\ 1-\frac{g_i(b)-g_i(a)}{t_i}\right]$$

C. In order to prevent the case which the divergence is too unfavourable, the fuzzy discordance relation (D_i) is produced as following definitions. In terms of threshold values, next section will mention.

$$D_i(a,b)=\begin{cases}1, \text{ if } g_i(b)-g_i(a)<t_i'\\ 0, \text{ if } g_i(b)-g_i(a)>t_i'\\ \textit{between } 0 \text{ and } 1, \textit{ otherwise}\end{cases}$$

For $g_i(b) - g_i(a)\ \varepsilon\ [t_i, t'_i]$ the decrease of $d_i(a,b)$ can be determined by linear interpolation or any other formula as follows:

$$D_i(a,b)=\left[\ 1-\frac{g_i(b)-g_i(a)}{t_i}{}'\right]$$

D. Fuzzy concordance relation C(a,b) can e produced with the value of P_i which are normalized as same process in step 2. $C(a,b)=\sum_{j=1}^{m} Pi\ di\ (a,b)$ is defined. Also fuzzy outranking relation d(a,b) is defined as following manner:

$$d(a,b)=\begin{cases}C(a,b), \quad \text{if } C(a,b)>D_i(a,b)\\[2ex] \dfrac{C(a,b)\Pi[\ 1-D_{i*}(a,b)]}{1-C(a,b)}\\ \quad, \textit{with } i^*\varepsilon D_i(a,b)>C(a,b)\end{cases}$$

E. The following fuzzy domination relation d^D , and the complementation operation d^{ND} in the fuzzy set theory are produced based on the methodology.

$$d^D(a,b)=\begin{cases}d(a,b)-d(b,a), & \text{if } d(a,b)>d(b,a)\\ 0, & \textit{otherwise}\end{cases}$$

$$d^{ND}(a,b)=1-d^D(a,b)$$

F. The fuzzy set of non-dominated design alternatives is determined by intersection operation between fuzzy sets in the following ways:

$$\begin{aligned}\mu^{ND}(a)&=\min\ d^{ND}\ (a,b)\\ &=1-\min\ [\ 1-d^D(a,b)\ ]\\ &=1-\max\ d^D\ (b,a)\\ &=1-\max\ [\ d(b,a)-d(a,b)]\end{aligned}$$

where $\mu^{ND}(a)$ represents the non-domination degree of design alternative (A_j) simultaneously by all the other design alternatives. The interpretation is that the $\mu^{ND}(a)=1$ define the unfuzzy set of nondominated design alternatives. Consequently, the nontransitivity of d(a,b) may give rise to the empty set of design alternatives for which $\mu^{ND}(a)=1$. This value identifies the optimal design alternative.

3. Evaluation

Since there have been many researches searching for the selection of optimal or best design alternatives. Most of studies are founded as statistical, fuzzy, possibilistic, minimax techniques which are performed under uncertainty. However, when the design attribute utility values are determined, the selection of design alternatives is getting easier regardless cost and tine considerations. Mathematical programming such as mixed integer programming or p-median programming only select the design specifications with the attribute utilities are determined and network decomposition method reduces the number feasible component eliminating the unnecessary components. Of the previous example, if designer selects designs for each design specifications rather than design alternatives, then alternatives' utility value is 2.895 (the lowest is 2.348). While the proposed optimal design alternatives' utility value is 2.644 (the lowest is 2.543), this selection also shows the highest utility value among design alternatives. The design evaluation index (DEI) can be 2.664/2.895 = 93.18 (%) based on the following definition:

$$DEI = \frac{\text{selected optimal design alternative's utility value}}{\text{possible the best combination of design attribute utility value}}$$

The advantage and disadvantages of this study are described as follows :

Advantage

1. The systematic approach to product design views the design process as stepwise, and evolutionary process that gradually refines the design transformation from a set of customer requirements to a set of feasible design requirements.
2. The utilization of design attribute values incorporate numerical values rather than rely on unstructured decision making process.
3. Components reduction gives rise to decrease cost and tine constraints.
4. Grouping design alternatives provides simplicity

Disadvantages

1. The model and methodology presented here is particularly effective for design problems with a recognizable set of initial description.
2. Design alternatives combined components may cause less choice variability of special designs, or some combination problem may rise.
3. Knowledge-based expert experience is required to complete various steps of optimization procedure to product design.

4. The overall design process requires accurate information for the designer to be able to render a reasonable judgement about the generation of optimal design alternatives, feasible design specifications.

4. Conclusion

The presented methodology and model provides a systematic approach to the optimization of product design where various constraints associated with a concurrent engineering environment. Future research directions are supposed to be explored further in the area of fuzzy theory for the design selection under the uncertainty.

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