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A Framework of Set-based Concept Selection for Risk Control of Product Development

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Abstract: Product development (PD) projects are generally very risky because there are tremendous uncertain factors to handle. On the other hand, point-based product concept selection is always taken as the mainstream in PD practice to reduce resources consumption or expected lead time, which will inevitably introduce extra uncertainty into the PD process. This paper proposes a new framework of set-based concept selection in PD to improve the probability of project success. It suggests enhancing the decision robustness of product concept selection by allowing parallel evolvement of multiple alternatives, and the size of alternatives group will be re-determined at the next stage by assessing the overall quality of acquired product information at the current stage. The proposed method could provide PD team or manufacturers an optimal solution by balancing resources consumption and robustness of PD project success.

Keywords: Concept Selection, Set-Based Concurrent Engineering, Robust Decision, Risk Control, Product Development

1 INTRODUCTION

There are piles of decisions to make along the entire process of product development (PD) [1], and concept selection which begins at the early stage of product development is always treated as one of the most important decisions. At the stage of Concept Development, an initial set of design alternatives are created for selections and improvements. After that, a single product baseline is always frozen, as in common PD practices, at the very early stage (normally the stage of conceptual design) to be further developed for the fulfillment of requirements by the customers of target market segment. Each alternative is evaluated based on certain selected criteria, and the “best” alternative is identified and other alternatives are considered “inferior” and discarded meanwhile. Some researches even argue that the specifications of the product under development should be clearly defined at the beginning to discipline the subsequent PD process for “internal certainty” [2]. However, the highly dynamic market could make this “internal certainty” extremely risky in the context of “external

uncertainty”. It can be reasonably assumed that both early selection of the product baseline and early definition of the new product suffer from a great amount of uncertainty due to information scarcity. For example, the market requirements may be changed, or the gathered data used for selection decision may be inaccurate or even incorrect. Such an early selection could cause a very high risk of leading the PD project to a total economic failure, particularly for the breakthrough products. As a matter of fact, most companies give greater preference to developing incremental innovation products, instead of breakthrough ones, with being averse from the unmanageable risks of possible failures. Unlike many other companies which tend to quickly converge on a solution (a point in the solution space) and then refine it iteratively to meeting the requirements, Toyota delays the selection of the best alternative by co-developing a set of possible designs (a set in the solution space), which is termed Set-Based Concurrent Engineering (SBCE) [3]. SBCE assumes that reasoning and communicating about sets of ideas leads to more

robust and optimized systems, which finally provides greater overall efficiency than point-based design. Pugh's controlled convergence [4] also supports such set-based decisions. Meanwhile, set-based PD shares the same philosophy with the established paradigm of platform-based product development [5], while the former is focused on enhancement of project performance through risk control, and the latter on reduction of cost and lead time through commonality for product competitive advantage.

Estimations at the early stage have a high tendency of being inaccurate due to vague knowledge on the available concepts [6]. Thus, it is argued in this research that the selected "best" alternative could have a high probability of actually becoming inferior to other alternatives, e.g. technical infeasibility or poor profitability of the selected concept may not be identified until more accurate information has been acquired. Therefore, the inaccuracy of an early estimation due to insufficient information must be taken into consideration of concept selection decisions. In other words, the selection of design alternatives should be treated as in a statistical sense, rather than in a deterministic manner. Set-based practices have a higher probability to avoiding converge on the inferior choice especially for development of high-novelty products. This paper is trying to develop a reasonable framework to guide set-based product development in a quantitative manner. This framework could provide an optimal PD scenario in terms of concept selection decisions with constraints of limited PD resources, e.g., project budget.

DEFINING THE RISKS TO CONCEPT SELECTION

There are two measures of the risk in the estimation and comparison of design alternatives [7]:

The choice made is not the best based on the information available;

Once a decision is made, the outcome will not turn out as expected.

In this research, these two risk measures are respectively referred to as robustness probability (RP) and technical performance risk (TPR). Risk reduction could be achieved by acquiring new information. The higher information quality requires more cost and time but improves the estimate for reducing previous

risk. To handle this tradeoff, an optimal policy should be investigated to present a budget allocation profile for the PD processes to maximize the risk reduction for a given total budget.

2 DECISION-BASED DESIGN WITH UTILITY ANALYSIS

Decision-based design (DBD) models design as a decision-making process, which is structured to handle the design environment characterized by ambiguity, uncertainty and risk [8]. DBD with utility analysis can support identifying alternatives worth further analysis through tradeoff evaluation, and it also provides methods to model uncertainty effect on rank order of alternatives. In short, DBD can present a systematic framework for improving evaluations and providing reliable selections among the design alternatives.

3 THE FRAMEWORK OF SET-BASED CONCEPT SELECTION FOR PD RISK CONTROL

The whole scenario of this research, shown as in the figure 1, can be divided into two general phases, which are, respectively, 1) a rational selection of design concepts, and 2) an optimal budget allocation for maximum risk reduction. In general phase 1, a set of initial design concepts is created by designers according to customer requirements. Integration of multi-attribute utility analysis with risk modeling method is made to measure the value and uncertainty of each concept by expected utility (EU), TPR and RP, respectively. A reasonable selection strategy could be constructed based on these metrics, which turns out a subset of prior concepts. In general phase 2, it includes all of the subsequent PD processes before manufacturing. At each process, a possible investment budget is assigned to acquire the corresponding quality of information, which reduces the risks of the selected concepts to an extent. Since the total budget for PD project is constrained, the approach to allocate the budget along the processes would affect the amount of risk reduction. An overall mapping of "investment budget possible quality of acquired information expected amount of risk reduction" needs to be identified. Plus, learning effect needs to be considered in multiple concepts co-development, which tends to decrease the required investment per concept to achieve a certain level of information quality. Therefore, a proper subset size with allocated investment budget for each PD process can be decided for the total maximum amount of risk reduction within the whole PD project.

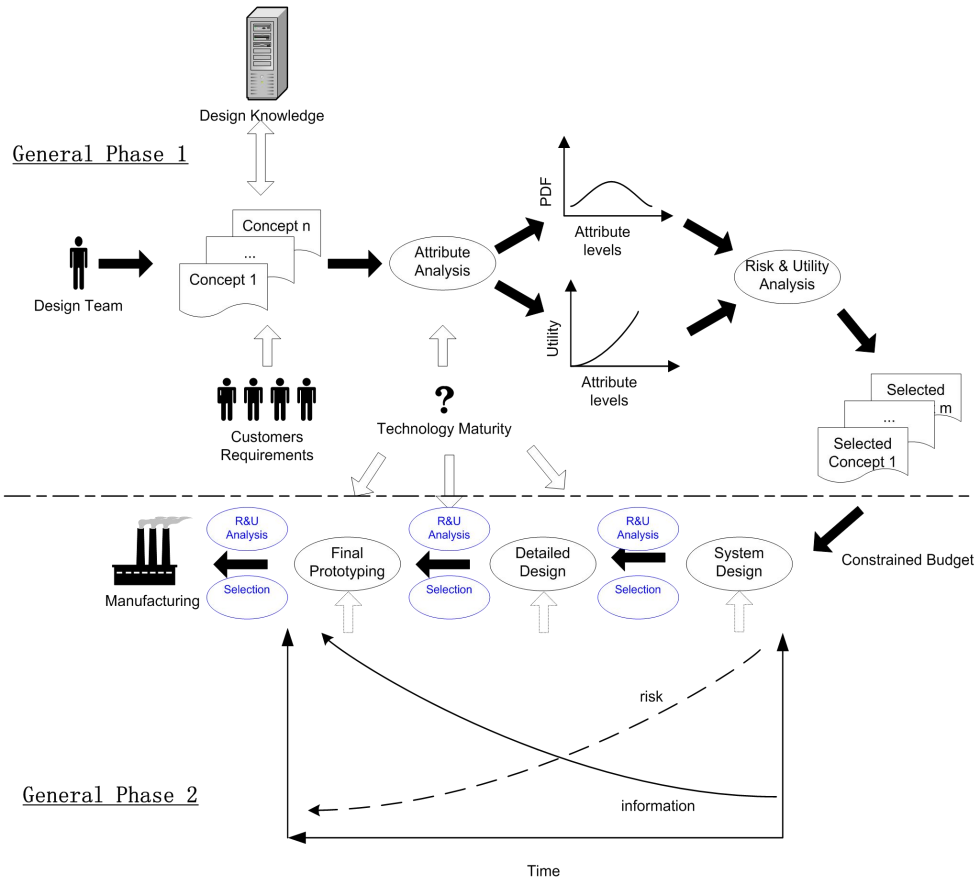


Figure 1. The overall scenario of risk mnagement

Normally, the total budget for a product development project is constrained. If the project duration is divided into a group of sequential phases, the information quality profile along these phases decides certain amount of total risk reduction, thus an optimal solution exists to maximize such total risk reduction. If information acquisition technology (e.g., physical/virtual prototyping, CAE) keeps the same efficiency, the information quality at the check gate of each phase can be controlled by increasing or

decreasing investment for information acquisition. Therefore, there exists such an optimal budget profile (investment percentage) along PD project phases that the total risk reduction can be maximized. In other words, the following questions will be answered: shall we choose to spend the same amount of investment on higher quality of information for a single alternative, or on a subset of alternatives with compromising information quality? If it is the latter, what is the optimal subset size for the next phase?

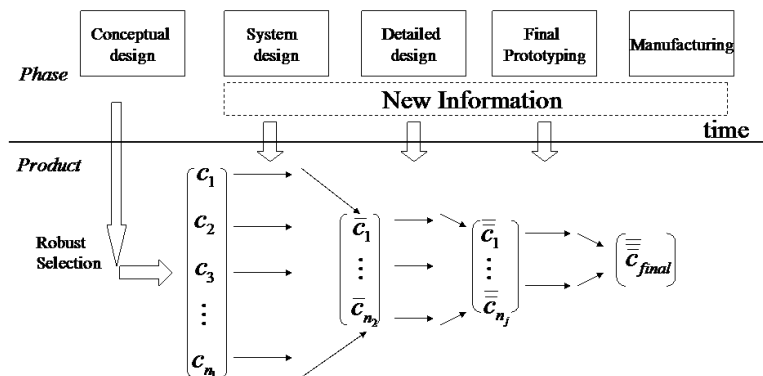


Figure 2. An illustration of optimal scenario for set-based concept selection

Hereby, the whole scenario of this research can be depicted as follows.

Input: a set of alternatives with the evaluation of attribute levels; expected utility (including the effect of environmental risk), technical risk, and robustness probability are calculated based on current estimations.

Decision variables: the optimally selected alternatives at the early stage to make sure the least sensitivity to future uncertainty; budget percentage and subset size of selected alternatives at each phase; in a more complex consideration, the number of phases along the whole project can be treated as additional decision variable;

Constraints: threshold level of decision confidence (maximum acceptable risk); fixed total budget; maximum and minimum accessible information quality in each phase;

Output: an optimal set-based scenario of alternatives selection under uncertainty at the early stage; an optimal profile of budget percentage and subset size along development phases that provides maximum risk reduction to ensure a robust selection and development of design alternatives.

Conclusions

The concept selection are amongst the most important decisions of PD projects. It begins at the early stage of PD project, thus its results will affect or even determine if the PD project could succeed. Although point-based practice is traditionally dominated among manufactures, external variable market environment makes it very risky. This paper proposes a new framework of set-based concept selection in PD to improve the probability of project success by introducing flexibility and adaptability into decision process. By allowing parallel evolvement of multiple alternatives, the concept selection will be made in a set-based manner with variable group size of concept subset, controlled by product information quality and allocated budget at each PD process. In this sense, the proposed decision framework is more towards the track of information-driven decision postponement. Detailed meta-modeling and several industrial cases will be the focus in future research.

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