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Modeling tradeoffs in three-dimensional concurrent engineering: a goal programming approach

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Abstract

This paper proposes a goal-programming modeling approach to address three-dimensional concurrent engineering (3D-CE) problems involving product, process and supply chain design. The model enables straightforward representation of the interrelations among multiple objectives and analysis of tradeoffs among those that exhibit conflicts. The model is demonstrated through a discussion of integrality versus modularity in product and supply chain designs that is motivated by events that took place in the automotive industry over the last decade. A numerical example is used to illustrate the model and the paper concludes with possible extensions and guidelines for implementation.

Keywords: Goal-programming; Supply chain design; Concurrent engineering; Integrality; Modularity; Tradeoffs modeling

1. Introduction

Competition in the marketplace forces manufacturing firms to continuously generate new (and more attractive) product designs while maintaining high quality, low costs and short lead-times. The imperative of smaller batch sizes, coupled with unique advantages of suppliers specializing in particular areas, drive such firms to outsource a growing portion of their product components and sub-assemblies. Traditionally, decisions on these issues were taken in a serial pattern. First, a product design was selected from a set of feasible designs, driven primarily by marketing objectives and engineering constraints. The chosen design was then transferred to the production planning function that developed an appropriate manufacturing plan. Such plans were guided primarily by operational objectives (e.g., cost minimization, capacity utilization, load balancing, etc.). Finally, the product design and the production plan decisions became constraints for the logistics function that determined the supply sources. This serial pattern is known to generate solutions that suffer from two major deficiencies (Gunasekaran, 1998). First, it is slow because parallel processing opportunities are often missed. Second, it leads to sub-optimal

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solutions, because each stage can make, at best, sequential locally optimal choices.

Concurrent engineering (CE) is a paradigm aimed at eliminating such flaws. CE dictates that product and process decisions are made in parallel as much as possible and that production considerations be incorporated into the early stages of product design. The CE concept leads to a fundamental tradeoff. On one hand it reduces the need for re-design and re-work (thus reducing development time) and increases the chances for smoother production (thus helping to minimize cost and improve quality). On the other hand, CE complicates the design problem as it requires joint optimization of a more complex objective with a larger set of constraints (Wu and O'grady, 1999).

Most of the CE research to date has focused on combining production considerations with product design issues (see, e.g., Stahl et al., 1997; Taylor, 1997; Smith and Eppinger, 1998; Chang et al., 1999; Sun et al., 2001). This two-dimensional approach (2D-CE) has led to many useful procedures such as *virtual prototyping* and *rapid prototyping* (see, e.g., Chang et al., 1999). CE applications were reported to achieve a 30–60% reduction in time-to-market, 15–50% reduction in life cycle costs and a 55–95% reduction in engineering change requests (Bopana and Chon-Huat, 1997).

Studies that stress the need to incorporate supply chain issues with product design and production planning (thus creating a three-dimensional concurrent engineering (3D-CE)) have started to emerge only recently. Fisher (1997) suggested matching the supply chain with the product structure. He defined products as either functional or innovative and proposed corresponding functions (either physical or mediation) for the supply chain. Eversheim et al. (1997) proposed a 3D-CE system that incorporates measures such as responsiveness, time-to-market, cost, quality and life cycle considerations. A comprehensive discussion of the 3D-CE approach was first given by Fine (1998). Feng et al. (2001) formulated a model that simultaneously determines the tolerances in the product design and selects the suppliers for the various components. With the exception of the last reference, the 3D-CE studies described above provided *qualitative* insights into the problem. None of these studies offered a unified quantitative methodology that can be used to analyze various 3D-CE tradeoffs.

The purpose of this paper is to close this gap by proposing a *quantitative* model to address various issues of 3D-CE. The common thread of these issues is the potential conflict among objectives. For example, from the logistics point of view, one might like to select the lower cost supplier to provide each component. But, low-cost components can often be associated with low quality and long lead-times thus creating a conflict with the product designer (who might prefer expensive suppliers associated with high quality or suppliers known for their excellent development capabilities) and the process designer (who is typically interested in short and reliable lead-times). Capacity utilization is another potential area of friction. The production department may seek to reach optimal utilization levels of the various production resources, while the logistics department seeks to reduce the risk of production stoppage by qualifying and utilizing a second source.

The model we propose may fit into several managerial process contexts. First, it can be integrated within the stage–gate procedure that was proposed by Cooper (2001) for product development processes. The first two stages in this five-stage procedure determine the scope of the new product and its basic business plan. The gates in each stage filter out proposals for new products that do not meet predetermined criteria. Our model can serve well the third stage where a detailed product and process designs are developed. The multiple objectives in our model can represent the multiple agents that Cooper envisions as taking part in this development stage (customers, technical development personnel, production engineers, etc.). Also, to fit with Cooper's iterative scheme for this stage, rather than running the model once to obtain a single best solution, we can run it iteratively where each time we run it again we change some of the parameter values in response to feedbacks obtained from the participating agents. The second context in which our model may fit is the set-based design methodology (Ward et al., 1995; Liker et al., 1996) for project selection processes. The set-based methodology urges designers to explicitly communicate with others on a set of designs rather than on a specific design. The set is gradually narrowed through eliminating inferior alternatives until the final solution is obtained. Our model can be easily incorporated within the set-based methodology by running it