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Enterprise-wide modeling & optimization—An overview of emerging research challenges and opportunities

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Abstract

The process systems engineering (PSE) as well as the operations research and management science (ORMS) literature has hitherto focused on disparate processes and functions within the enterprise. These themes have included upstream R&D pipeline management, planning and scheduling in batch and continuous manufacturing systems and more recently supply chain optimization under uncertainty. In reality, the modern process enterprise functions as a cohesive entity involving several degrees of cross-functional co-ordination across enterprise planning and process functions. The complex organizational structures underlying horizontally and vertically integrated process enterprises challenge our understanding of cross-functional co-ordination and its business impact. This article looks at the impact of enterprise-wide cross-functional coordination on enterprise performance, sustainability and growth prospects. Cross-functional coordination is defined as the integration of strategic and tactical decision-making processes involving the control of financial and inventory flows (both internal and external) as well as resource deployments. Initially, we demonstrate the existence of cross-functional decision-making dependencies using an enterprise network model. Subsequently, we discuss interactions between enterprise planning decisions involving project financing, debt-equity balancing, R&D portfolio selection, risk hedging with real derivative instruments, supply chain asset creation and marketing contracts which influence decision-making at the activity/process level. Several case studies are included to re-enforce the point that planning and process decisions need to be integrated.

Keywords: Supply chain management; Enterprise modeling; Risk management; Product pipeline management

1. Introduction

Globalization trends have significantly increased the scale and complexity of the modern enterprise. The enterprise has been transformed into a global network consisting of multiple business units and functions. Operational functions include R&D pipelines, production networks (both batch and continuous) and supply chain networks. These functions are supported by financial planning and marketing strategy functions. The enterprise is exposed to internal and external uncertainties. Examples of internal uncertainties include success prospects of R&D projects due to technological risks; production upsets such as batch failures and plant shutdowns. External uncertainties include pricing related uncertainties for raw materials and products (unless the firm is operating in a monosopny or a monopoly), exchange rate fluctuations, market size and demand uncertainties due to competition and macro-economic factors. Process enterprises respond to the evolving business and technology environments by strategic maneuvers involving R&D, manufacturing, supply chain and marketing functions. Strategic maneuvers involving R&D include capital budgeting, R&D project selection and project commercialization. Strategic maneuvers involving the manufacturing function include capital project planning, risk management and financing. Strategic maneuvers involving the supply chain function include distribution asset creation as well as supply chain risk management. Strategic maneuvers involving the marketing function include contracts design and management. Strategic decisions answer the question—“What should the enterprise do to attain strategic goals?”. In addition, tactical decisions must answer the question—“How should the enterprise execute strategic decisions?”. Tactical R&D decisions include project scheduling and R&D resource management. In recent times, strategic and tactical R&D management has been termed as Innovation Process

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Management (IPM). Tactical manufacturing and supply chain decisions include batch plant scheduling in response to forecasted demands, production asset management and selection of energy feedstock in response to market prices. Traditional PSE and ORMS literature streams tend to focus on sub-sets of these decisions whereas an enterprise functions as a cohesive entity with several degrees of cross-functional co-ordination. Often lack of such cross-functional co-ordination leads to loss of short and long term value. Further, organizational complexity tends to challenge much of our understanding about cross-functional coordination and its business impact. Hence, from the enterprise-wide performance viewpoint, it is sub-optimal to optimize strategic and tactical decisions in a disparate fashion as has been done hitherto in the literature. At the same time, integrated enterprise-wide decision-making is significantly more challenging in comparison to function-specific decision-making. In fact rigorous literature on enterprise-wide modeling is very sparse.

The goal of this paper is to demonstrate that integration of enterprise decision-making leads to substantial value creation. By doing so, we hope to motivate a strong case for development of models that will efficiently integrate decision-making related to R&D, manufacturing, supply chain and marketing functions and help in enhancing our understanding of co-ordination across these functions. The paper does not cover research opportunities in the area of enterprise-wide work practices/systems which is closely related to implementing the enterprise-wide optimization strategies proposed in this paper. These practices/systems include robust and reliable data acquisition systems, development of human skills required to drive the proposed enterprise-wide coordination strategies and real-time modeling and solution systems that can help managers test/develop their insights with formal decision models without the need to understand formulation and algorithmic details. We feel that these issues are too extensive and critical to be covered in a single paper and justify and indeed require separate treatment. The paper is organized as follows: We present an overview of strategic and tactical decision models developed in the Operations Research-Management Science (ORMS) as well as process systems engineering (PSE) literature. The models reviewed are those that in our view are expected to play significant roles as components of enterprise planning architectures. Section 2 presents a critical review of the relevant ORMS literature. Section 3 presents a critical review of the relevant PSE literature. Section 4 presents an enterprise network model that conceptualizes the need for integration of decision-making. Section 5 presents a discussion supported by examples on the integration of capital budgeting and R&D Project Prioritization. Section 6 presents a discussion supported by examples of integrating resource allocation, manufacturing and scheduling decisions under uncertain R&D environments. Section 7 presents several examples on the integration of supply chain components such as risk hedging contracts, integration of production and inventory network decisions, integration of production and capacity planning decisions, integration of production and marketing strategy decisions. Section 8 presents an outlook on computational strategies for enterprise wide modeling and optimization. Finally, Section 9 summarizes our perspective on the upcoming research area of enterprise-wide modeling and optimization.

2. The ORMS strategic and tactical literature

A comprehensive enterprise-wide modeling framework requires a unification of methodologies developed in corporate finance as well as the operations research and Management Science (ORMS) literature. Hence, we present separate surveys of the strategic and operational literature.

2.1. Strategic enterprise models

Strategic enterprise models (also called capital budgeting models) were devised to build enterprise portfolios that ensure long-term value creation. The earliest capital budgeting models were based on pure economic analysis (Chapman & Ward, 1996). The Discounted Cash Flow (DCF) method remains the most commonly used technique (Krishnan & Ulrich, 2001). However, it is based on expected values of uncertain parameters and is unable to generate quantitative details about the risk associated with a given project (Poh, Ang, & Bai, 2001). While simple from every aspect, the DCF method has been criticized on several counts. The DCF method fails to account for uncertainties in the costs as well as commercial returns. The method simply uses the expected values of the probability distributions modeling these variables. Further, most real investment projects include several decision-making flexibilities embedded within their execution structure. For instance, decision-makers have the flexibility to discontinue funding a project if a competitor captures an unacceptable share of its market segment. Such flexibilities are commonly termed as “Real Options” referring to options on real investments (Pindyk & Dixit, 1994). Failure to incorporate the value generated by such options leads to undervaluation of the investment project. The DCF method also has been criticized for its rigid focus on single criterion decision-making versus more realistic multiple criteria decision-making (Linton, Walsh, & Morabito, 2002). Thus, a method is required that can incorporate project uncertainties, multiple reward and risk criteria as well as embedded options.

Efforts to solve this problem have been collectively termed as decision theoretic methods (Morgan & Henrion, 1990; Nutt, 1998). Decision theory formalizes the key concepts of risk and return by defining the decision-maker’s utility function (Markowitz, 1991). Using this formalism, decision theory provides comprehensive portfolio management methods such as decision trees which allow management to undertake complex resource allocation decisions between competing product candidates with full consideration to the possibilities of product failures (Sharpe & Keelin, 1994). The decision tree method also has addressed portfolio management issues such as how many projects to pursue and how many projects to terminate (Ding & Eliashberg, 2002). From a conceptual point of view the Decision tree method is a manifestation of Stochastic Dynamic Programming (Bertsekas, 2000). Roberts (1999) presents an interesting account of market competition related risks to profitability in the pharmaceutical industry. One of the most comprehensive multi-