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Applying complexity science to new product development: Modeling considerations, extensions, and implications

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ABSTRACT

We extend the popular NK model of complex landscapes to incorporate two realities of NPD: (1) complementary vs. conflicting dependencies in a project and (2) predominantly incremental design changes to components in evolutionary NPD projects. We show, through stylized projects that the nature of dependencies among system elements moderate the effect of system complexity. Our study highlights that NPD development times may be longer than the original NK model suggests. We offer a modeling framework that can be used to test hypotheses regarding actual systems. Finally, we discuss promising directions for future research.

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Introduction

The development of new products is a source of competitive advantage for firms. New product development (NPD), however, is often viewed as a "messy and complex" process involving many engineers and managers responsible for designing components that interact to perform a desired set

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of functions. Such complex systems are comprised of ''a large number of parts that interact in non-simple ways'' (Simon, 1969, p. 195). In Simon's definition, ''non-simple'' implies that interactions among elements of the system are uncertain and, as a result, often produce surprising, unanticipated outcomes at the system level. We, therefore, do not view NPD as a linear set of activities (which many models and tools used in NPD and project management often assume, e.g. Gantt and PERT charts). Rather, we see NPD as a complex adaptive system (McCarthy et al., 2006) in which macro scale properties of a system/process cannot be inferred from properties of its constituent parts and rules of their interaction.

As an example of complexity in NPD, consider the development of a new aircraft. Such a project typically involves hundreds of engineers and managers working in teams. The efforts of these varied teams (e.g. fuselage, flight controls, wing assembly, etc.) can be conceptualized as a complex system in that decisions made by an agent (an individual or a team) not only affect their own component's design but often influence the relative performance of other components due to interactions and dependencies between and among components. Thus, the development efforts of each component are both variable and interdependent. This coexistence of variation and dependency is a hallmark of complex systems across many domains (Shalizi, 2006).

Early research on NPD attempted to characterize product development and management as a logical and ordered process (Zaltman et al., 1973; Cooper, 1990) that took inputs (requirements) and used resources (engineers and managers) to produce output(s) in the form of new products (Clark and Wheelwright, 1993). However, researchers and practitioners have concluded that NPD is typically more complex. Thus, NPD efforts instead follow a less deterministic path consisting of rework, restarts, iterations and changes (Leonard-Barton, 1988; Cheng and Van De Ven, 1996; Smith and Eppinger, 1997; McCarthy et al., 2006) as agents, teams, and decisions interact. In order to better understand the dynamics of NPD projects and the organizations that engage in NPD, recent research has looked to the relatively nascent field of complexity science for insight and understanding (e.g. Anderson, 1999; McCarthy et al., 2006; Baumann and Siggelkow, 2013; Akgün et al., 2014).

In this paper, we investigate the phenomenon of complex NPD project dynamics using the framework of the popular NK model. To aid our understanding, we incorporate and explicitly model two important contextual realities of the NPD process to specifically account for (1) varying degrees of complementary and conflicting dependencies within NPD projects and (2) predominantly incremental component level design changes in NPD projects.

This study produces three insights. First, we find our extended NK model and simulation results suggest the nature of dependencies between system elements can moderate the effect of system complexity: when a system has a low degree of complementary dependencies, system performance is relatively unaffected by complexity, but when that same system contains a moderate to high degree of complementary dependencies, system performance increases with increased complexity. This insight is counterintuitive in that it is widely believed that more dependencies in a system have a universally deleterious effect. Second, our study highlights that NPD development times may be longer than the original NK model suggests. When we model component changes using a skew triangular distribution, as opposed to the uniform distribution specified in the original NK model, we find development times are longer and system improvements are more incremental. This is an important insight because the NK model's popularity and widespread use in the field of management science may lead some to draw conclusions regarding NPD applications when, in fact, conclusions could be additionally informed by this research which highlights a key difference regarding development times. Finally, the extensions to the NK model in the present study uncover the tension between development time and product quality that is inherent in NPD, whereas previous studies using the NK model have reported little regarding the relationship development time and complexity. Specifically, we find the level of complementary dependencies in a system not only moderates the effect of complexity on system performance, but also moderates how complexity impacts the trade-off between system development time and system performance: when complementarities are few, as complexity increases, system performance declines but system development time is reduced; however, when complementarities are many, both system performance and system development time increase as a function of increased complexity.