2008

Design reuse in manufacturing and services

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Most professionals, actively engaged in design, live in a world of trade-offs. The most typical compromise is that reducing the cost of design causes quality to suffer, but there are many others as well. This paper summarizes current use of one of the most popular approaches to improving the new offering development process: design reuse. In the present study 42 companies were surveyed, of which 23 were in manufacturing and 19 were in services—but all were actively engaged in technology and design reuse in new offerings. It was hypothesized that policies for design reuse and internal sourcing would promote the complexity and breadth of reuse (here the combination of modular and architectural substitution), which, in turn would dampen the percentage of substitution and reduce the negative impact on innovativeness of new offerings. These predictions were generally supported. Adoption of policies for encouragement or to mandate design reuse were significantly correlated with the extent of reuse (application of both architectural and modular design vs. just one or the other) among manufacturers but not services firms in the sample. Internal sourcing of ideas for design reuse was significantly correlated with extent of reuse for the total sample, and especially for services. Design reuse percentage and extent of design reuse were significantly and inversely associated for manufacturing, as predicted, but not for services. Novelty of new offerings was significantly and inversely related to percentage of reuse, as predicted, for manufacturing, but not for services. It was found that sector also makes a difference in likelihood of adopting higher levels of reuse with service company respondents reporting significantly higher levels (average of 42% reuse for services and 28% for manufacturing applications). Perhaps one of the most interesting preliminary findings to emerge was that the tipping point of negative impact from design reuse percentage on innovativeness for all firms in the sample of new offerings was 43%, beyond which novelty suffers. For manufacturing, the tipping point was lower: Novelty begins to suffer after 33% design reuse, which has important management implications. The conclusion was drawn, based on these preliminary results, that much can be done to relieve some of the negative consequences of the typical trade-offs commonly encountered in development programs for new offerings, especially when cost, timing, and innovation are the target goals. However, services and manufacturing are quite different in their approach to design reuse and substitution. Further development of the concept of design reuse strategy appears to be warranted based on these preliminary findings. The findings raise the distinct possibility that mesolevel strategic

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* Work in this area was supported in part by the Technology Management Center, E. Philip Saunders College of Business, Rochester Institute of Technology. We are grateful for the suggestions made on the revision of this manuscript by Professors Richard N. Osborn, Vadake Narayanan, Frank T. Rothaermel, two anonymous reviewers, and the editor. Data for this project were originally collected via Mr. Osman Tasci's M.S. thesis in information technology at Rochester Institute of Technology.

aggregation issues might lead research into areas that help explain how complex systems realize their full self-organizing potential and why corporate strategy considerations, alone, have failed to explain the success and failure of organizations coping in rugged landscapes.

Introduction

Design reuse continues to be one of the primary methods companies use to reduce the cost and timing problems of new offerings, with systematic concern for this process going back well over a decade (e.g., Arango, Schoen, and Pettengill, 1993). In a more recent example, for a firm that makes printed circuit boards it was estimated that 90% of new boards involve some type of design reuse (Incorvaia, 2005). Yet the first challenge of any product development effort is widely understood to be the consideration of trade-offs, like the work of Ulrich and Eppinger (1995, p. 5): "An airplane can be made lighter, but this action will probably increase manufacturing cost. One of the most difficult aspects of product development is recognizing, understanding, and managing such trade-offs in a way that maximizes the success of the product." In particular, the present paper is more interested in the issue of cost and time reduction from design reuse and its potential impact on the innovativeness of new products and services.

BIOGRAPHICAL SKETCHES

Dr. John E. Ettlie is the Malelon L. and Richard N. Rosett Professor in the Saunders College of Business at Rochester Institute of Technology. He earned his Ph.D. at Northwestern University in 1975 and has held appointments since then at the University of Illinois Chicago, De Paul University, the Industrial Technology Institute, the University of Michigan Business School, the U.S. Business School in Prague, Catolica University in Lisbon, Portugal, and Visiting Scholar at Deusto University in Bilbao, Spain. Dr. Ettlie has published more than 80 refereed journal articles and conference proceedings. He has authored six books, including the second edition of his textbook to be published by Elsevier (April 2006) titled *Managing Innovation*. His current research interests include service innovation, comparative studies of idea sourcing of successful new products, thinking style, all aspects, upstream (supply chain) and downstream (commercialization) of the new product development, and lean research and development (R&D), especially as it relates to the new approaches to sustainable management of scarce resources.

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Although some recent works have documented the problems of design reuse (Ball et al., 2001; Busby, 1999), few studies have investigated the relationship between reuse practices and the resulting innovativeness of the new offering derived from reuse. Furthermore, most studies on the topic of reuse have predominately dealt with problems involving computer software and architectural reuse (Frakes and Kang, 2005; Rothenberger, 2003; Sherif, Appan, and Lin, 2006; Van Ommering, 2005). It is already expected, based on published reports, that design reuse will be used to reduce cost and to shrink time to market with new offerings (Griss, Jacobson, and Jonsson, 1997; Nazareth and Rothenberger, 2004). The question raised here is does this hurt the innovativeness (novelty) of new offerings? For example, the number of reused intellectual property blocks in chip design and the semiconductor industry has risen sharply to cope with market instability and cost pressures (e.g., Benkowski, 2004), but little or no systematic information exists on the impact of these reuse decisions on the novelty of recent product and service offerings.

Sector is clearly a distinguishing factor when it comes to the topic of reuse. For example, Mercedes-Benz, in an effort to improve quality and reduce cost, has reorganized its product development process around six cross-functional teams (e.g., power train, design, electronics). Instead of vehicle programs developing components separately, the goal is to share more parts across vehicle lines (Meiners, 2005). How do they intend to avoid the obvious problem that this restricts creativity in finding the best component for the particular vehicle? The answer given is that program managers can now concentrate on areas that are unique to their models making project management more efficient and accountable.

There is also an intergenerational effect: Engineers at Mercedes-Benz can identify a more focused set of components to use from outgoing models. Again, the idea is that constraining the design process can set engineers free to be more creative in unique parts of total product characteristics. The benefits of planning include the synergistic effects that this example illustrates. However, how to achieve this benefit is unclear, and this can vary within sectors as well, when divergent requirements are encountered by project type and supplier choice and involvement (Whyte, 2003).

There is evidence that service-sector application of design reuse is quite different than what one typically sees in the manufacturing and construction environment. Meyer and DeTore (2001) rationalized the concept of service reuse through the development of reinsurance platforms used by an insurance company, Lincoln Re. They proposed that although service offerings are coproduced with the customers (Gustafsson and Johnson, 2003), most offerings are developed by utilizing a common framework that can be applied to a variety of services the firm offers. This framework begins by identifying customer problems and then looking at traditional solutions used in the past by the firm. In the case of Lincoln Re, once they saw that past service solutions would not work, they developed new offerings geared to specific customer preferences by resegmenting the way they viewed the reinsurance marketplace.

Although the historical origins of formalized design reuse can be traced to the 1940s with Cambridge University's reuse of subroutines in computer software code (Lim, 1998), today relatively little is known about the innovation trade-offs that result from general reuse practices in the manufacturing and service industries. Cost, efficiency, and quality (Ball et al., 2001) continue to be the most common factors that the majority of engineers and managers attempt to balance during the design process, with the resulting novelty rarely considered.

Hypothesis Development

In the context of a company's operating environment, there are many ways to frame the problem of design reuse (Griss et al., 1997). This study focuses on the organizational issues that can affect reuse choice and outcomes, most specifically the policies and strategies that companies set with regard to this practice.

Busby (1999) studied reuse problems within two separate, medium-sized engineering firms. He found that the highest percentages of problems were not caused by engineering or environmental factors but rather by organizational factors. In fact, he found that approximately 40% of problems encountered during reuse, within both firms, were caused by organizational factors and barriers. This might be expected since managers are often held accountable for the success of individual projects while failing to look at the larger picture of reuse as a company-wide process, which requires the constant support of management to succeed (Griss et al., 1997).

Strategy and Design Reuse

The focus in this paper is on the organizational issue of formalized (written) polices for design reuse. The precedent for this attention, of course, comes from the long tradition of strategic impact of derived and adopted policies of cost controls and diversification on organizational outcomes such as retained earnings and innovation (Schilling, 2005). For example, most design reuse is a modest exercise in search for quick solutions for cost and timing problems. An exception is Sun Microsystems, which has adopted a broader, more far-reaching strategy of extreme reuse of an entire 64-bit central processing unit (CPU; Wilson, 2003).

Having a strategy allows companies to make better use of the tools they employ in the new product development process (Shrivastava and Souder, 1987), especially when it is essential to integrate customer needs with research and development (R&D) capabilities. However, there is little systematic evidence of the impact of these strategies related to design reuse and outcomes.

Perhaps the most important potential contribution of the current study would be in providing a starting point for a better understanding of the role of strategy in the innovation process as it is executed in design reuse decisions. The present study draws heavily on trends in two relatively unrelated fields: *knowledge reuse* and the application of complexity theory in *corporate strategy* and leadership.

Knowledge reuse. Theory of knowledge reuse typically emphasizes information technology mediation and how repositories of information are created and accessed. Markus (2001) referred to these as organizational memory systems, and the goal of such theory development is the eventual design of systems to make them more efficient for reuse—the sharing and transfer of knowledge being the most desirable outcome here. Markus identified four stages in this process—capture (documentation), packaging, distribution, and reuse—and added to this three major roles in knowledge reuse: producer, intermediary, and consumer. Knowledge reuse situations vary greatly by how much functional independence there is between these roles (e.g., shared work practitioners), which is most akin to the context chosen in this study for design reuse. However, there are many others, including secondary knowledge miners, and many situations involve more than one context. Central to the Markus treatment and concerns of the present research is the cost of making and using information, because the most prevalent motivation for knowledge of design reuse is cost saving. Markus (ibid., p. 79) argued that one of the most significant costs involved in reusing information is that producers document data to suit themselves and not potential reusers. Incentives can be applied to overcome some of these problems, but distance and the need to maintain legitimate intellectual property rights to protect knowledge can be formidable. The role of intermediaries is taken up in the following sections as a factor in one empirical study of knowledge reuse.

The importance of knowledge reuse—that is, the process by which an entity is able to locate and use shared knowledge, according to Majchrzak, Cooper, and Neece, (2004, p. 175)—is derived from the notion that the creative potential for innovators (progenitors of new products and services) is enhanced to the extent that they can reuse other's knowledge previously unknown to them. Empirically (six case studies), it has been found that if radical innovation is sought, the reuse-for-innovation process is enhanced when a significant performance gap is identified, when an adapter exists to bridge the gap between source and recipient, when search and metaknowledge are enhanced, and, finally when problems are redefined in nontraditional ways (ibid.). Several of these findings are applied herein in the developing hypotheses—in particular, the need for innovation in knowledge reuse contexts.

Corporate strategy. One segment of the strategic management literature is beginning to exhibit dissatisfaction with the pace of theoretical development in the field; it is now offering, for example, alternative models of adaptation and can potentially inform the notion that execution of strategy will have an enormous impact on the innovativeness of the firm. This stream of research applies concepts of complexity theory in corporate strategy (e.g., Caldart and Ricart, 2004; Levinthal, 1997; Levinthal and Warglien, 1999) and the application of these contributions to leadership theory (Marion and Uhl-Bien, 2001; Osborn, Hunt, and Jauch, 2002).

The important outcomes of these contributions help to inform the present model of the potential diminishing returns of design (an application of knowledge) reuse on innovation outcomes. Starting with the basic notion of complexity theory that systems are self-organizing, the notion of landscapes at the organizational level is introduced. A landscape is characterized by two dimensions, where the number of policies or action choices (N) is one dimension and the number of elements in each choice is the other dimension (K). As the interactions between these two dimensions increases, the interdependencies between policy choices increases, and the landscape with both dimensions becomes quite complex, or rugged (Caldart and Ricart, 2004). There are short and long jumps possible to accomplish goals—in this case and for purposes herein, incremental and radical (innovation) moves.

Caldart and Ricart (2004,p. 99) defined corporate strategy as decisions made for the purpose of driving, pacing and framing the firm's evolution. In the context selected here—design reuse and the strategy thereof—this is an execution variable that involves multifunctional, coordinated action for selection of the scope and depth of design reuse decisions. Decisions involve, at a minimum, both architectural design of products (not structure as they have it) and modular or subsystem component design. Cognition is not included in the present study's execution variable as it is preset in the model and corporate search strategies are really manifest in these choices for scope and depth. For the time being, technology or design sourcing is separated out as a distinct variable (see following discussion), as this is normally how these decisions are deconstructed in practice. But this does not mean they could not become part of a more global variable later in this research stream.

The important contribution of complexity theory for strategy and the implications for design reuse policies is that the firm is being guided between two extremes that threaten survival in increasingly turbulent, risky (uncertain), and complex environments. These two extremes are the *competency trap,* which in this paradigm means climbing a local mountain of goal attainment but ignoring global optima, and the *chaos trap,* which happens when cultures go too far in rule breaking and undefined jobs and structures.

The construct of redesign policy is conceived here to be a multifunctional, execution plan that bounds activities of knowledge use on one or many platforms of a product or service, new or existing for the organization. Functions typically involved, regardless of sector, would be *marketing, technical* (R&D and engineering), and *operations* (manufacturing), and perhaps *quality*. For assembled goods, this would also include *purchasing* and supply chain management and, perhaps most importantly, *information technology*.

The role of redesign strategies (Collett, 2001) in this regard is to provide the firm with multifunctional execution options that avoid either of these extremes (competency or chaos traps), that enhance requisite variety in a way that promotes learning, and that ameliorate excess on trade-offs among cost, timing, and innovation outcomes. This is akin to the "patching" or bridging to the future that tries to find a reasonable compromise between global and local search. In other words, firms that have a design reuse strategy must formally articulate levels of scope and scale or, here, modular and architecture of product (not of organizational structure—that is an outcome of strategy). This formalization allows execution in a way as to avoid ambiguity and excess repetition of designs and steers a course of pacing, framing, and driving toward a happy "medium", which Osborn et al. (2002, p. 803) called dynamic equilibrium controlled by leaders exert pressure on strategies. Excessive reuse of designs reduces costs while sacrificing innovation; excessive innovation compromises standardization and efficient use of R&D resources.

Therefore, the following hypothesis is offered for testing:

> *H1: Firms that have a policy or strategy for reuse are likely to execute broader application of the concept, expanding explicitly on several types of reuse (e.g., modular and architectural), and eventually, the extent of reuse will increase but only up to a point where diminishing returns to innovation are realized.*

The belief here is that design reuse has the potential to become self-contained and is not suboptimized when there is an explicit strategy for these practices. It is assumed, for the present study, that the consistent alignment with corporate and business unit strategy are at minimum sought here (Owen, Burstein, and Mitchell, 2004), although this is not the explicit focus of the study. From case history data, it is known that strategies for design reuse are often embedded in methodologies, many of which emphasize greater speed and, of course, cost reduction in the design cycle (Fields, 2000). It is argued later that design reuse policy has the ultimate effect of acting as a *strategic (framing) lens* to focus knowledge (design) reuse efforts to balance cost reduction without degrading innovation outcomes of products and services.

It is also expected that this effect will be moderated by sector. Within manufacturing, for example, chip manufacturers may be reusing as much as 50% from previous circuitry but still missing original schedules 80% to 90% of the time (Fields, 2000). Service firms are far less likely to formalize policies (Martin and Horne, 1993). Therefore, the strength of this effect is predicted to be much stronger in the more complex new product sector of manufacturing.

A plausible rival hypothesis is that emergent practices rather than formalized strategies explain this same effect of policy-driven combination of modular and architectural reuse. This is essentially what happened at Black & Decker approximately 15 years ago when competitive pressures on cost forced the company to seek varied and drastic measures to improve product value. In the process of communizing part numbers across more than one product category, Black & Decker found that combining both platform and modular reuse saved considerably more time and money in the process, even though there was no formal policy to pursue these two avenues of reuse (Ettlie and Stoll, 1990). It remains to be seen if these emergent practices are formalized in companies, but the fact that these practices might accomplish the same outcome, at least temporarily, does raise the prospect of confounding results.

Sourcing Strategy and Type of Reuse

One way of attempting to defeat the trade-off of timing, cost, quality, and innovation is to source reuse designs and technology internally. When companies involve suppliers and customers in the new product and new service development process, it slows the process down. So sourcing broadly but confining the search process to just internal design reuse can save time but can still have the same broad effect, as it did in the Black & Decker case (Ettlie and Stoll, 1990). It is possible, of course, that this might restrict the number of or variance in ideas for reuse, but if both modular and platform (architectural) reuse is pursued, this potential negative effect might be postponed. Therefore, a second hypothesis is offered for testing:

> *H2: Firms that source design reuse ideas primarily from internal platforms and modules achieve a broader application of the concept, expanding to several types*

of reuse because of the tendency to exploit rather than to explore concepts at this stage of development.

The rationale for this second hypothesis is not obvious but involves understanding at least three important factors underlying this process. All are based, however, on the idea that exploitation tends to trump exploration in most companies, which are dominated by local (less costly and less risky) search behaviors (Caldart and Ricart, 2004). First, as illustrated in the Black & Decker case, companies can "discover" a reuse policy through aggressive practices of reuse, and internal sourcing of ideas will promote faster application of the approach so more experiments can be done in the same period of time and can promote creativity to make up for the possible diversity of ideas that might accrue by working with outsiders (e.g., suppliers). A more recent example is the platform extension of the Evinrude E-TEC two-stroke outboard motor across several horsepower ranges, or families of engines (Banse, 2005), even though several publications have argued the difficulty of capturing design intent with design reuse using the current tools and methods available (Versprille, 2001).

Second, although outside influences might promote wider diversity of ideas considered, this practice might also degrade focus in the design process as well as add time to the process. Therefore, the most effective way to creatively promote the design effort is to adopt several types of internally driven reuse sourcing (i.e., modular and architectural).

A third possible explanation for the dominance of internal design reuse sourcing is that external sourcing does not allow as much creative adaptation of designs because suppliers or customers may retain intellectual property rights to these inputs (Sandler, 2001). Design verification can account for 50% to 80% of product development time (Moretti, 2000), which will also discourage outside collaboration in redesign.

No prediction is made here as to whether controlling for sector will matter in this case, since product and especially service design reuse are so poorly understood as of this writing. However, the intention is to see if moderating effects do operate here.

Design Reuse Type versus Percentage of Reuse

Two of the most common categories or types of reuse are architectural and modular. Architectural reuse can be defined as changes to the way a system is put together, without a change to its components (Henderson and Clark, 1990). A widespread example of this type of reuse deals with computer code. Organizations create libraries to house different subsystems made up of computer code. With policy and planning, companies with a strategy are able to take these subsystems and arrange them into larger subsystems (Lim, 1998) to create programs. One subsystem can be used to create an endless number of other systems (programs).

On the other hand, modular reuse can be defined as reusing the components that make up a service or product in the design of another service or product. This practice is best shown across product platforms. Take, for instance, Black & Decker's revival by utilizing common motors and components throughout its power tools line. Meyer and Lehnerd (1997, p. 9) chronicled their design of a "common" 650 watt motor that was developed for use in a platform for their power tools division. Before the modular reuse of these motors, Black & Decker was reported to have more than 120 different motors for its various consumer power tools. With modular design reuse, significant cost savings were realized (ibid., p. 10).

Imagine a company trying to reuse millions of lines of computer code without having a policy or strategy that delegated responsibility for development of particular subsystems. It would likely end in failure or take far too long to accomplish to be economically feasible. This represents a trade-off between the extent of strategy-driven design reuse and the amount or percentage of substitution.

An extreme example might help to illustrate this tendency. In custom chip design, no chip is 100% unique, or entirely custom, even though this is what makes it appealing to customers (Johnson and Ettlie, 2001). Certain design blocks are frequently reused, which is common in datacom and telecom applications; platforms constrain the amount of reuse that is possible, which actually makes the total product delivery easier. So the following is proposed:

H3: The greater the extent of design reuse (combinations of modular and architectural reuse) the more likely there will be less substitution or percentage of reuse of individual elements because of the constraints imposed on the design system.

Another way of stating this hypothesis is that breadth of reuse will reduce the amount of straight substitution in any given instance. The rationale for this hypothesis rests in part on the relationship between policy driven (general management inspired) design reuse and middle management and technical personnel response to more general goals of cost reduction as opposed to innovation. Not only do these two levels in a firm have different roles in fostering new offerings (Ettlie and Subramaniam, 2004), but, depending upon sector, the locus of information sourcing will also favor one of these groups over another (Ettlie and Elsenbach, 2007). In manufacturing, technical bench staff (engineering and R&D) and technical managers, as well as marketing, will be favored for successful idea sourcing. In services, the locus for ideation of successful new offerings shifts to general managers. So not only does this illustrate how there might be a trade-off between policy-driven extent of design reuse and proportion of designs reused, but it is also likely that controlling for sector will be paramount to predicting the outcomes of design reuse.

The second rationale is based on the notion that discipline in design affords greater creativity and that the benefit comes from innovation, not from amount of substitution. That is, as the extent of policy-driven reuse is defined it constraints the percentage of reuse because the product must be reassembled in a system (Scharf, 2003). This interaction between the need for systems integration and constraints that stimulate creativity is well known in theory (Ettlie and Stoll, 1990) and practice (Meiners, 2005).

Design Reuse Percentage and Innovation

R&D productivity has become a key issue in managing technical resources. For example, *Research-Technology Management*'s 2004 forecast for R&D trends (Johnson, 2004) showed that member firms surveyed are quite concerned about this issue. Perhaps most importantly, the results of this recent survey showed that since 2000 companies have decreased both their R&D spending as a percentage of sales as well as overall levels of spending.

Although design reuse can help to bring about decreased development costs and decreased development time, what has been the impact of design substitution on other outcomes like quality and innovation? Fleming and Sorenson (2001a, 2001b) found, through an in-depth analysis of U.S. Patent Data, that modular reuse can result in "breakthrough" products. However, these breakthrough products were few and far between, and they found that modular reuse activities had invariably "undermine[d] the innovation process by reducing the opportunities for breakthrough advances (Fleming and Sorenson, 2001b, p.21)."

Woodfield, Embley, and Scott (1987) found that software designers who were untrained in reuse made decisions that were influenced by unimportant features of reusable elements yet were uninfluenced by the important features (Busby, 1999). In the absence of policy-driven design reuse, cost will dominate reuse decisions. Moreover, Busby found that increased levels of reuse had actually increased designers inhibitions. Designers were forced to constantly compare their portion of the design with the portion that was reused. This resulted in designers feeling that no matter what they did, their designs would not "measure up" to those that had preceded them.

These examples lead to the premise that using both architectural and modular reuse in the design process might be more costly but could enhance creativity through focus and constrain the design process effectively. Focus on reuse alone without strategic focus could degrade creativity (Meiners, 2005):

> *H4: Higher proportions (percent) of design reuse (without the bounding conditions of policy-driven limits on extent of reuse) will lead to less innovative products or service being developed.*

The resulting model of four hypothesized relationships, controlling for sector context, is presented in Figure 1. The single most important feature of this model, which considers all four hypotheses together, is the indirect impact that policy-driven extent of reuse is likely to exert on novelty by reducing the negative impact of percentage reuse on innovativeness of new offerings. Note that H3 and H4 are both inverse predictions, which in sequence would reverse an otherwise negative impact on outcomes. The present paper makes the argument that design reuse policy has the ultimate effect of acting as a strategic (framing) lens to focus knowledge (design) reuse efforts to balance cost reduction without degrading innovation outcomes of products and services.

Two other findings were expected to be replicated from the literature: (1) Firms would report their primary reason for reuse as a cost or time reduction; and

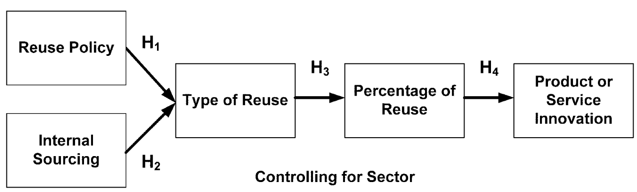


Figure 1. Proposed Causal Model

(2) service sector firms would engage in higher percentage levels of reuse because of the greater average simplicity of their offerings and the general lack of formalization of their strategies (Martin and Horne, 1993). This is one of the major reasons sector was used as a moderator in testing all four hypotheses. Results are reported next.

Methodology

This study used a Web-based questionnaire (see Appendix) posted through an online benchmarking survey service site called Surveyor (http://www.benchnet.com), which has 30,000 members worldwide. The pros and cons of a Web-based survey were considered. The benefits, when compared with pen-and-paper surveys, include quicker acquisition of data, less cost, and fewer missing values. In contrast, Stanton (1998) found the cons to include more anonymity on part of the surveyed subject, less assurance that the survey will be answered by an intended recipient, and statistical uncertainty of differences between sample means between Web-based and pen-and-paper surveys. However, both types of surveys remain consistent in the collected data's covariance structure and the factor structure of items forming a scale (ibid.). To ensure that questions of this particular survey were understood by the respondents, the surveyor used as many questions as possible from past scholarly surveys. For example, the self-reported measure of new product or service novelty was used in past surveys (e.g., Ettlie and Rubenstein, 1987; Ettlie and Subramaniam, 2004). The 15-question survey was offered to site members for a three-week period that ended in early November 2005. Of the 46 responses registered on the site, three were eliminated because they were duplicates of other survey respondents and contained only the responders' e-mail addresses. One other survey response was declared ineligible because it reported a new offering but did not incorporate any design reuse. This gave an effective response rate of 0.14% (42 of 30,000). Overall, a total of 19 responses were classified as new service offerings, whereas 23 were classified as new manufacturing offerings.

Companies involved in the manufacturing sector mainly involved those involved in the automotive and industrial manufacturing industries. The manufacturing companies included two divisions of Xerox, Dana, three divisions of TRW, Mersey (watches), and Johnson Controls, as well as companies in the semiconductors, chemical, and food industries. On the other hand, the service firms involved in this survey encompassed a variety of business and financial services (insurance, investment, and consulting). The service firms can also be said to incorporate a mixture of businesses that sell to consumers, to other businesses, or to both.

The breakdown of respondents by percentage was as follows: 55% general managers, 14% middle managers, 19% technical staff and others, and 14% no title reported. Subtle instances of reuse were prominent within cases involving reuse in the service industry. Some examples were reusing a contacts database for marketing of another service and the customizing of training videos to fit the needs of particular customers. Manufacturing reuse was more elaborate in that it often included products with complex subsystems or components. These included the reuse of components for the design of a new parking brake, seatbelts, and tire inflation monitoring system.

Testing for Method and Sampling Bias

Given the relatively low response rate, it was necessary to determine how representative the sample was and if the results could be generalized to some population of firms. Since the benchmarking website was maintained for that specific purpose, there was no major concern with the normal issues of response bias since salience of the issues is the typical reason people respond (Stanton, 1998).

Nonetheless, to test for nonresponse bias, a method often used, especially in the marketing literature, was adopted suggesting that subjects who respond late are more like nonrespondants (Armstrong and Overton, 1977; Chowdhury and Miles, 2005). These two studies compared early and late responders using selected comparisons of means for the first one third and last one third of the responses received.

There were no statistically significant differences between the means of the first one third (14 responses) and the last one third of the response questions dealing with the four variables in the study: reported level of novelty of the new offering, reuse percentage, reuse extent, or policy (Table 1). Measures of these variables are presented next.

Measures

The questions on this survey and coded variables are given in the Appendix. Companies were asked to give

Table 1. T-Test for Bias

Variable	t	df	Significance (Two-Tailed)
Policy	0.391	26	0.699
Reuse Extent	1.122	26	0.272
Reuse Percentage	– 1.004	26	0.325
Innovation	0.862	26	0.396

the name of the product or service that they developed by way of design reuse. If there was no specification as to whether it was a product or service, the name of the newly developed offering was reviewed and coded as either a product or service. All reported offerings were then checked as to which sector was applicable.

Reuse policy was captured with responses to one question early on the survey: "Was there a corporate or business unit policy on design reuse at the time you began developing this product/service?" This was coded 1 for yes and 0 for no. Of all the cases, 12 of 42 (29%) reported having a formal policy for reuse, and 9 of these were manufacturers.

Extent of reuse was captured from data resulting from answers to the question on type of reuse: "If yes, would you describe this design reuse as ___________?" Answers were forced into one of three categories: "architectural" was coded 1; "modular" was coded 2; and "both" was coded 3. Extent was then constructed from these responses: either architectural or modular was coded 0; and "both" was coded 1. Various coding combinations were experimented with and evaluated so as not to miss any subtle effects in these data (e.g., Was modular more "difficult" than either architectural or both?), but none resulted form the sensitivity analysis. The number of firms that reported using both architectural and modular reuse was 20 (47%), and 22 of the firms (51%) reported using either architectural or modular.

Internal sourcing of reuse ideas was captured with one proportion estimate question: "The primary source of reuse was internal___% or external___% of the total reuse portion." The mean internal percentage sourcing was 55.5% (median = 50%, with a standard deviation of 37.6%).

Reuse percentage was coded as the decimal that resulted from the answers to the following question: "What was the % of overall design reuse level in this new product/service in terms of *cost* _______?" The mean reported reuse percentage based on cost was 34.2% (median = 30%) for 42 cases, with a standard deviation of 22.4%.

Product or service innovativeness was captured using an item from the literature (e.g., Ettlie and Rubenstein, 1987; Ettlie and Subramaniam, 2004): "Was the product/service ……..?" This question was coded with the following response categories: 5 = new to the world; 4 = new to the industry; 3 = new to the organization; 2 = significant upgrade of existing product/service; and 1 = minor modification of existing product or service. The mean innovation level reported on this scale for novelty was 3.1 (standard deviation [SD] = 1.1), with a median of 3.0, which is the theoretical mean of the scale.

Validation of the Dependent Variable

The dependent variable was the degree of innovation or novelty level of the new product/service offering. This variable was validated using two self-reported control variables: R&D ratio (R&D spending as a percentage of annual sales) and product age. R&D ratio and offering novelty were significantly correlated, with a Kendall τ-c value of .282 ($n = 36$, $p < .01$); two-tailed tests were used unless noted. Likewise, R&D ratio and product novelty had a Kendall τ-c value of .370 ($n = 18$, $p = .01$). Second, product age was also significantly correlated with novelty of the resulting offering, showing that older product lines led to less innovative offerings. The Kendall τ-c for all firms was not statistically significant, with a value of – .207 ($n = 42$, $p = .07$). However, the Kendall τ-c value for manufacturing firms was statistically significant, with a value of – .298 ($n = 23$, $p = .01$).

The distribution of the manufacturing dependent variable cases ($n = 23$) for this study was compared with previously published use of this same scale (Ettlie and Subramaniam, 2004) of similar sample size ($n = 21$). The mean comparison of these two samples resulted in the following values: $t = .324$, $p = .747$, and df = 42. Therefore, the assumption was made that the samples are similar with regard to the average innovativeness of new manufacturing offerings.

Perceived benefits of design reuse were captured using a series of prompts following the question, "What were the direct benefits of design reuse? Please select all that apply and explain" (Table 2):

(a) Cost reduction, if selected what %?
(b) Faster time to market, if selected what %?
(c) Better system integration, if selected, explain.
(d) Focused our attention on a few critical elements.

Table 2. Reported Benefits of Reuse

	Number of Cases	Cost Reduction (%)	Faster to Market (%)	Focused Innovation (%)	Shortened Testing (%)	Quality Improvement (%)
All Cases	42	67	79	36	48	40
Manufacturing	23	74	74	35	61	43
Service	19	68	68	42	63	42
Reuse Policy	12	92	92	67	50	33

(e) Allowed systems thinking, if yes, explain.
(f) Shortened testing time, if yes, explain.
(g) Quality improvement.
(h) Ease of manufacturing.
(i) Other (e.g., indirect benefits like methods improvement?) If yes, explain.

Validation of the R&D Ratio

As mentioned in the previous section, self-reported R&D percentage was used to validate the self-reported level of novelty. These self-reported levels of R&D ratio were compared with archival entries in published R&D sources. The R&D percentages (dollars spent on R&D over the total sales for the most recent year) of 11 respondents' firms were taken from Schoenfeld & Associates, Inc.'s (2005) latest compilation of R&D ratios and budgets. Schoenfeld's methodology for developing these ratios begins by finding the most recent R&D ratio of a company. That ratio is then applied to estimates of forecasted sales to estimate future R&D spending. This approach is strengthened by the fact that many companies base their R&D budgets on expected sales. As expected, there was a highly significant relationship between the self-reported R&D percentage and the verified R&D percentage, with Spearman $r = .702$ ($p = .016$, $n = 11$).

Again, the reader should be cautioned that these small sample results, in spite of these validity and intersubjectivity tests being positive, should be taken with extreme care and should be considered preliminary. As provocative as the findings are, they are based on a small, albeit representative, sample that begs creative replication.

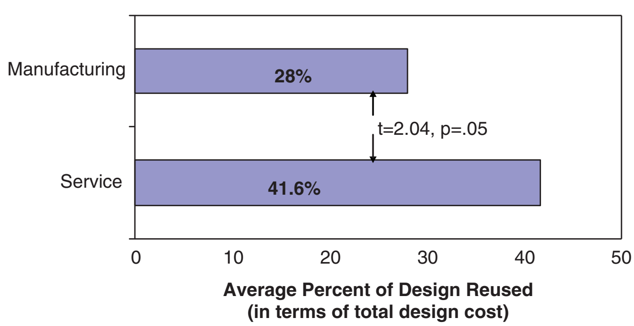
Results

In accordance with the study's prediction, cost savings and faster time to market were the two major benefits reported by respondents of this survey, regardless of sector. Specifically, manufacturing firms were found to report cost savings and faster time to market in nearly three quarters of the cases in this survey. More importantly, of the 12 firms having a formalized policy for reuse, 92% of them reported cost savings and faster time to market as the major benefits of reuse.

Service firms were more likely than manufacturing firms to use design reuse to a higher percentage in the development of new offerings (Table 3). A correlation run between sector and reuse percentage supported this, with a Kendall τ-c value of $-.417$ ($n = 42$, $p < .01$). Furthermore, a mean comparison test revealed that the average service offering had reused approximately 42% of its past designs, whereas manufacturing offerings reused an average of 28% of past designs in development of new products, which was statistically significant ($t = 2.04$, df $= 40$, $p = .05$). The average R&D percentage (as portion of total sales) for a manufacturing firm in this study was 8.9%, whereas the service firms had an R&D percentage of 7.1%. The slight disproportion of means between sectors was not statistically significant ($t = -.281$, df $= 36$, $p = 0.78$).

Of the 42 companies surveyed, only 12 had a formal policy or strategy for dealing with design reuse in the organization. Companies with a strategy appeared to be predominantly manufacturing, with service firms comprising only 3 of the 12 total firms having a formal one. This result is consistent with the findings

Table 3. Sector and Reuse



of Martin and Horne (1993), who found that service firms are likely to lack a strategy or policy for creation of new offerings.

Testing Hypotheses

Table 4 reports the results of hypotheses testing. H1 was strongly supported by the results controlling for sector. Reuse policy and extent of reuse were significantly correlated for manufacturing ($\tau = .45$, $p < .01$, one-tailed test). Manufacturing firms with a reuse policy are significantly more likely to broadly implement reuse, employing both modular and architectural substitution from previous practice.

H2 was strongly supported for the entire sample ($\tau = .43$, $p < .01$) and as moderated by sector, with the surprising result that service firms are more likely than manufacturing to increase extent of design reuse (i.e., to use modular and architectural types) by internally sourcing ideas ($\tau = .58$, $p < .01$).

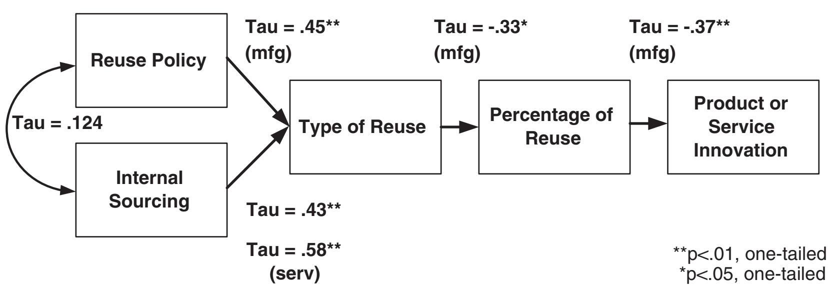
H3 predicts that extent of reuse and percentage reuse would be inversely related, and they were, but just for manufacturing ($\tau = -.33$, $p < .05$, one-tailed test). That is, as the extent of reuse increases in manufacturing (not services), the proportion of substitution of old designs declines. Extent trumps "blind" substitution as predicted in the case study literature.

H4 predicts that higher proportions of design reuse will lead to less innovative offerings. When all cases were considered, Kendall τ was not significant, with a value of $-.171$ ($n = 42$, $p = .207$). However, when just manufacturing firms are considered, the resulting relationship was significant ($\tau = -0.37$, $p < .01$, $n = 23$, one-tailed test). This supports the notion that the negative impact on innovation of cost-related measures of proportion of design reuse is usually confined to complex products and is less likely to be either offered or compensated for later in new service offerings. Independent effects of these two predictors (reuse policy and internal sourcing percentage) were tested for, and it was found that they contributed uniquely to the reuse extent. First, the two predictors are not significantly correlated: $\tau = .124$ (n.s.); τ for service $= .244$ (n.s., $n = 19$); and τ for manufacturing $= .025$ (n.s., $n = 22$). Ordinary least squares (OLS) regression accounted for a significant, independent variance in extent of reuse ($R^2 = .20$, $F = 4.68$, $p = .015$; internal percentage Beta $= .385$, $p = .012$; reuse policy Beta $= .183$, $p = .218$). Recall that only manufacturing reuse policy is significantly correlated with extent of reuse in the model (Table 5). Independent effects of these two predictors (reuse policy and internal sourcing percentage) were tested for, and it was found that they contributed uniquely to the reuse extent. First, the two predictors are not significantly correlated: τ-c $= .124$ (n.s.); τ-c for service $= .244$ (n.s., $n = 19$); and τ-c for manufacturing $= .025$ (n.s., $n = 22$). Ordinary least squares (OLS) regression accounted for a significant, independent variance in extent of reuse ($R^2 = .20$, $F = 4.68$, $p = .015$; internal percentage Beta $= .385$, $p = .012$; reuse policy Beta $= .183$, $p = .218$). Recall that only manufacturing reuse policy is significantly correlated with extent of reuse in the model (Table 4).

Proportion of Reuse and Innovation

The question that emerges from this survey is at what point does design reuse bring about diminishing returns with regard to the innovativeness of new offerings? Meyer and DeTore (2001) pointed out the benefits of learning curves in the case of product platforms, where some executives proposed the "75% rule." This rule suggests that 75% of components

Table 4. Results



for new designs will come from a "repository of subsystems and interfaces" (p. 193). However, this rule fails to take the resulting novelty of a new product or service offering into account.

To help answer this question, innovation and reuse percentage were plotted against each other using a linear fit. The standardized regression coefficient for all offerings taken in this study is beta = – .270 ($n = 42$, $p = .083$ two-tailed, $p = .042$ one-tailed). The R^2 and R^2 adjusted values were .073 and .050, respectively ($F = 1.352$). Table 5 summarizes the results for the complete combined sample of new product and new services. For all offerings considered in this study, the point (level coded as 3 or "new to the organization" on the innovation scale) at which the fitted-line intersects and beyond was approximately 43% reuse.

For the second part of this analysis, service firms were removed from the sample to probe sector differences. Innovation and reuse percentage were plotted once more; however, this time only the manufacturing firms were plotted ($n = 23$). This resulted in an improved fit, with R^2 and adjusted R^2 values of 0.188 and 0.149, respectively ($F = 4.859$). The standardized regression coefficient for products is beta = – .433 ($n = 23$, $p = .039$ two-tailed). As Table 6 shows, the point of diminishing returns for reuse has dropped to around 33% by looking exclusively at new products. This indicates that manufacturing firms are more likely to have the resulting innovation of their products affected by a lower percentage of overall design reuse than service firms typically would. No direct comparison is available for services due to smaller sample size.

Table 5. Novelty of New Offerings versus Reuse Percentage (Total Sample, $n = 42$)

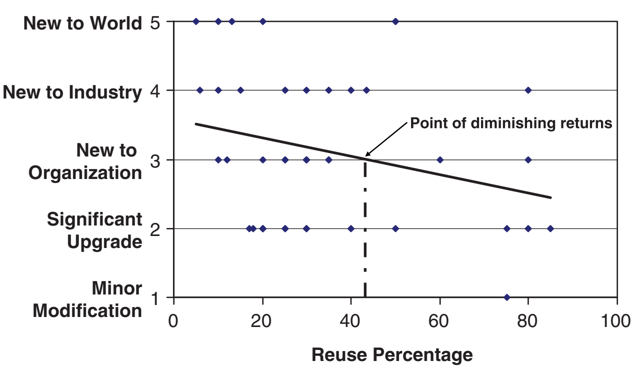
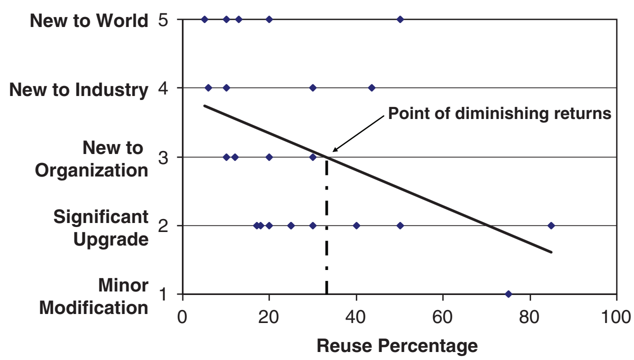


Table 6. Product Novelty versus Reuse Percentage for Manufacturing ($n = 23$)



Discussion

The present study tested and supported four hypotheses, with the intent of showing that extent of design reuse, whether policy driven, or internal sourcing driven, would limit the negative impact on innovativeness of new offerings. These results give preliminary evidence that although all designers live in a world of trade-offs, it is possible to make progress in limiting some of the negative trade-off results when cost and time reduction in development is the primary motive for design reuse. Furthermore, there are significant differences between service and manufacturing, which gives further, more tailored guidance in understanding the otherwise general advice often emerging in the new product development literature.

Perhaps the most important potential contribution of this paper is that the tipping point of reuse proportion for innovation appears to come much sooner that other writers might have imagined (about 33% on average). This ignores the variance, of course, of this finding. There is a range (Table 7) of impact in this result, from 55% at high and at a low of about 20%, which indicates that one size might not fit all. This also has important implications for future research: what accounts for this range of tipping point of negative impact of reuse on innovation across cases within and between industries.

Perhaps the single most important finding with theoretical overtones is the that design reuse policy has the ultimate effect of acting as a strategic (framing) lens to focus knowledge (design) reuse efforts to balance cost reduction without degrading innovation outcomes of products and services. This single important finding deserves continued development and empirical testing, since it is derived indirectly from the literature on complexity theory as it is embodied in corporate strategy and leadership. This finding raises the possibility that greater theoretical importance should be attached to this mesolevel of strategic aggregation, which involves multifunctional execution of corporate strategy not adequately covered in earlier treatments (e.g., Caldart and Ricart, 2004). This multifunctional strategic level of aggregation allows for complex systems to realize their full potential for self-organization and also explains why some efforts to guide complex systems in rugged landscapes with corporate strategy, alone, have failed: too little theoretical and practical attention to multifunctional execution of knowledge reuse issues.

Several limitations of the current study limit the ability to generalize results. First, a small sample of service and manufacturing companies goes beyond case studies but begs to be replicated in more and broader contexts. Second, the theory in guiding predictions limited the ability to account for outcomes such as the strong impact of internal sourcing on extent of reuse in services, and less so in manufacturing. In particular, the variable that shows the most consistent promise—reuse policy—is a construct derived from two relatively new research streams: knowledge reuse and the application of complexity theory to corporate strategy. The results are consistent, even with this limited sample, for manufacturing but not services, which suggests that the development of strategy is quite context specific, similar to the recent literature on leadership effectiveness (e.g., Osborn et al., 2002). The present paper has not touched on the formalization of information technology and its role in this reuse process, whereas several of the papers cited here convert policy and strategies into methodologies embodied in hardware–software systems (Koegst et al., 1998; Markus, 2001), and this clearly warrants attention. The shelving and unshelving of ideas, especially platform-related issues, might well be a part of this process and facilitated by information technology not attended to in the current research, especially for services (Meyer and DeTore, 2001). Finally, measures and triangulation using multiple methods need further improvement in future research.

Management Implications

Although we continue to live in a world of trade-offs when it comes to development of new offerings, we are not helpless—we can minimize the negative impacts of these trades and enjoy the benefits. In the case of design reuse, we can enjoy the improved cost and timing of new offerings, especially in manufacturing, without having to sacrifice innovativeness of new products. Both a formalized policy for reuse as well as emergent internal sourcing of reuse ideas can operate independently to contribute significantly to appropriate choices on extent (modular and architectural) of reuse.

However, one size does not fit all. The tipping point on diminishing returns to innovation averages about 33% (cost-wise) on substitution of previously used designs, but this outcome might range as high as 55% on the high end and about 20% on the low end. There is currently not any more improved information to provide, and clearly this is where judgment would enter into the development process. However, there are no innovative manufacturing cases above 55% in the present sample, which calls into question previously published guidelines that recommend as high as 75% reuse.

In services, the barriers to application of the principles of design reuse have been shown to be lower than in manufacturing, and internal sourcing has been shown to be a greater impact on extent of reuse when compared with manufacturing. However, knowledge about the impact of reuse decisions on innovation for services is still hidden, and more research will be required to find this tipping point—if there is one—and the circumstances under which it occurs.

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Appendix: Design Reuse Survey

DESIGN REUSE SURVEY

PURPOSE: This survey is being conducted to gain more insight on *design reuse* during *new product development*. The results will be kept confidential, no personal, company or product names will be associated with the data. This research will be used in partial fulfillment of a master's thesis at ___________. Survey is funded by________________. Contact information: _________: _______________. Copyright © __________, All rights reserved. This questionnaire cannot be reproduced without written permission of the authors.

INTRODUCTION: Design reuse is one of the potential methods companies use to improve the development process. Please take about 15 minutes and answer the questions below on design reuse. You will receive the results of this survey within one month. Thank you for your help.

Please take a moment and think back over the last few years to describe, in general terms, the last major new product introduced by your organization.

Your Name

Contact info (fax, email, phone)

Size of organization (number of employees)

Industry

Country

1 **What was the name of this product?**

2 **Is this new product typical of your line of business? (Yes, No)**

3 **How long have you offered products of this type? ________(years)**

4 **The primary customer for this product was (select one)**

a) Industrial

b) Consumer

c) Both

5 **What proportion of sales do you spend on R&D for this line of business?**

6 **The product was (select one)**

a) New to the world

b) New to the industry

c) New to the organization

d) A significant upgrade of an existing product

e) Minor modification of an existing product

f) other __________

7 **How successful was this major new product? (Select one)**

a) Extremely successful, returned a multiple of the investment, early.

b) Very successful, came in on time, on budget and met traditional internal rate of return expectations.

c) Successful, in the long run - took longer to return the investment but we learned a great deal from this experience.

d) Not successful financially, but we learned enough to move on.

e) A failure in financial and technical terms, we won't do this again.

8 **Did this new offering incorporate any design-reuse* ? Yes, No.**

(* Design reuse means, reusing existing design, which includes hardware, software, architecture or platform, in a new offering, as is or with minor modifications. Existing design could be internal to the company or external (e.g., Supplier).

9 **If Yes, how would you describe this design reuse as? Please circle only one answer:**

a) Modular (Component)

b) Architectural (Platform)

c) Both

10 **What was the % of overall design reuse level in this new product in terms of cost? ___%**
(For ex: Consider a new laptop which reuses the existing design of the harddrive (costs $10) and processor (costs $40). The rest of the new laptop is being newly designed. The new laptop costs the company $500. In this case, design reuse level in terms of cost is 10%; calculated as cost of reused design over total cost of product. ($10 + $40)/$500 = 10%.

11 **Was the design reuse a completely new application of the original concept? (e.g., decorative coating, reused as a lubricant)**
Yes, or No.

12 **The primary source of reuse was internal___% or external___% of the total reuse portion.**

13 **Did you encounter any unanticipated problems in modifying the design for reuse? If yes, please explain________________________________**

14 **Was there a corporate or business unit policy on design reuse at the time you began developing this product? Yes, No, If Yes, how did the policy influence your design decisions?**

15 **What were the direct benefits of design reuse? Please select all that apply and explain.**
a) Cost reduction, if selected what %?
b) Faster time to market, if selected what %?
c) Better system integration, if selected, explain.
d) Focused our attention on a few critical elements.
e) Allowed systems thinking, if yes, explain.
f) Shortened testing time, if yes, explain.
g) Quality improvement
h) Ease of manufacturing
g) Other (e.g., indirect benefits like methods improvement?) If yes, explain

16 **May we contact you for clarification if needed? Yes or No. Thank you for your help.**