INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD, CA, UNITED STATES

A Framework for Balancing Efficiency and Effectiveness in Innovative Product Design

Tucker J. Marion[1]
[1] Assistant Professor. 108 Stearns, Northeastern University, Boston, MA 02120 USA, Phone: (617) 373-2241, Email: t.marion@neu.edu

ABSTRACT
Improved design innovation through the use of new product development activities, methods, and tools has been an area of fertile research for the past several decades for both academics and practitioners. High-level management process study has given way to the development of detailed, quantitative tools and techniques whose mission is to enhance the process of innovation. This research seeks to understand the link between academic research and industry best practice. In this article, we report on the results of an empirical study of best practice design and innovation firms. State-of-the-art practitioners are balancing development efficiency and effectiveness by eschewing onerous methods and quantitative tools by adopting and adapting flexible processes and activities during product design. Resource draining methods and quantitative tools see limited use and are implemented only when necessary. A framework illustrating the need to keep design innovation on a critical path by balancing the efficient and effective use of activities, methods, and tools is presented. The paper concludes with directions for further academic research.

Keywords: innovation, product design, industrial design, new product development

1 INTRODUCTION
Design innovation via the new product development process has been well studied over the last forty years. The conceptualization, design, engineering implementation, and commercialization of new products has been studied across a broad range of industries [1],[2],[3],[4],[5],[6],[7],[8],[9],[10],[11],[12]. This body of work establishes effective approaches for developing new products, examining practices for defining new product strategy, undertaking user-centered design, managing architecture as well as enabling product platforms, manufacturing process design and measurement. This research has resulted in popularized methods such as gated development processes [9], design for manufacture and assembly techniques [4], voice-of-the-customer and quality function deployment [13], user-centered design [14], and structured innovation [15].

The process of design for innovation overtime has increased in complexity with research focusing on more advance tools, techniques, and models. These have included design structure matrices (DFM) [16], genetic algorithms for deconstructing design problems [17], and structured innovation techniques such as TRIZ [18]. However, the core of developing and commercializing new products and technologies – balancing form and function to enhance users' lives – has not changed. Accepted design practice includes a) extensive observation and depth interviewing with target users; b) iterative designing for style and form to please the eye of the user; c) iterative design to meet the functional requirements of the user with careful consideration of the materials, technologies, and components available to the firm by its own means or from suppliers; and d) finally balancing of the form and function to achieve a distinctive design and branding [19],[14]. The approach to this design process has been popularized by the success of design and innovation firms such as Continuum [20] and IDEO [21]. As with product development processes in general, the art and science of design is increasingly being modeled with formal steps and tools [22],[23],[24]. One can extrapolate that the process of design-driven innovation will be increasingly modeled with the goal of highly automated quantitative tools designed to produce better innovations. However, is that the right path? Arguably the most successful new product innovation introduced in the last ten years has been the Apple iPod. The design process for iPod product was very simple, led by a small core team that acted in an entrepreneurial fashion, unencumbered by onerous methods, tools, and quantitative analysis [25],[26]. In this paper, we seek to investigate the path of academic design research and compare versus practitioner state-of-the-art. We argue that there needs to be a balance between methods and tools and simplified processes for increased design innovation and project efficiency and effectiveness. In this paper, the context of balanced new product development and design innovation is discussed via results of an empirical study of design firms. A framework is then proposed that can foster increased innovation through straightforward and dynamic deployment and activities, methods, and tools. Finally, the paper concludes with discussion on future research.

2 RESEARCH MOTIVATION

In this paper we explore design innovation from an academic and practitioner perspective with the aim of increasing design innovation through the balance of value added activities and a la carte use of methods and tools. In order to accomplish this task, we begin by exploring state-of-art in research in design and product development. Next, we report on the results of a study of 44 design firms sponsored by the Industrial Designers Society of American (IDSA). The study was conducted in 2007 with a focus on mechatronic products. Finally, we propose a framework for the ground-level implementation of balanced design processes.

At its basic level, innovation is "a process that begins with an idea, proceeds with the development of an invention, and results in the introduction of a new product, process or service to the marketplace" [27]. Schumpeter [28], one of the original contributors to innovation, outlined two types: 1) entrepreneurial innovation and 2) managed innovation. This article focuses on the latter, managed innovation, and factors of success resulting from the implementation of design processes and methods. The activity of new product development (NPD) is a *process* in which resources are committed to an entity whereby the finished product has a tangible value to the consumer. In this article, we are focused on the process from conceptualization to design completion. In order to discuss the convergence of design processes into complex tools and methods, one needs to start at the highest level and NPD research and progress down to finite methods and tools.

At the managerial level, Cooper [9] outlines two fundamental aspects in product design that can mitigate the associated risks of commercializing successful products. These fundamentals are: 1) doing the *project right*, based on common success factors among successful NPD companies including cross-functional teams, up-front market planning, and early product concept definition; and 2) selecting the *right projects*. Cooper argues that product selection and product planning methodology are essential to a successful product launch and lifecycle. Krishnan and Ulrich [11] divided the development decisions within new projects into four main categories: concept development, supply-chain design, product design, and production ramp-up and launch. Ulrich and Eppinger [12] denote a generic development process, shown in Figure 1.

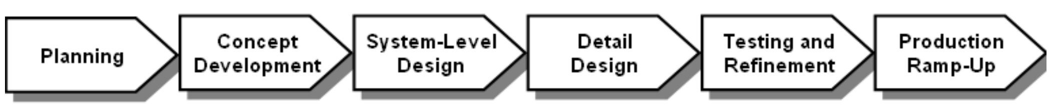

Figure 1. Ulrich and Eppinger (2004) NPD process.

In each of these phases, activities are performed by the development team. For example, in the planning phase, product and technology roadmaps are defined, the market and competitive space is explored, and resources are allocated. At the next level of systems engineering, methods have been developed to aid these activities. For example, market segmentation grids [8] were developed to help the companies plan product platforms and portfolios based on technology that can be leveraged to multiple subsystems and products. Taking a further step further, quantitative tools have been developed to quantify and automate these methods. In the example of product platforms, genetic algorithms have been developed to help guide and optimize product platform design decisions [29]. For each of the development phases in Figure 1, we map phase, activity, method, and quantitative tool for select design practices. These are shown in Table 1.

Table 1. Hierarchy of design – NPD phases to quantitative tools.

Phase	Activity	Method	Quantitative Tools and Techniques
Planning	Perform market research	Competitive evaluation	Product dissection (Marchese, et al., 2003), QFD (Hauser, 1994)
	Define product portfolio	Market segmentation (Meyer and Lehnerd, 1997)	Genetic Algorithm (Simpson, et al. 2001)
Concept Development	Define project scope	Structured brainstorming	Design synthesis techniques (Vico, et al. 1999)
	Develop concepts	Industrial design sketches and models	Multi-criteria decision making (Klein, 1993)
	Concept selection	Concept selection matrices (Ulrich and Eppinger, 2004)	Fuzzy decision models (Hayes and Akhavi, 2008)
System-level Design	Define subsystems and architecture	Engineering layout of modular systems (Ulrich, 1995)	Design structure matrix (Browning, 2001)
	Develop final concept	Industrial design concepts and models	Genetic algorithms for design innovation and selection (Goldberg, 2002)
Detail Design	M/ECAD	Product design using 3D software (Solidworks, Catia)	Automated CAD model construction (Lamecki and Kozakowski, 2003)
	Prototype testing	Physical testing and Finite Element Analysis (FEA)	COSMOS and ANSYS FEA (Rao, 2004)
	Kick-off tooling	Evaluate sourcing decisions	Cost and component evaluation modeling (Marion, et al., 2007)
Production Ramp	Product cost and margin analysis	Perform bill-of-materials and supply chain cost analysis	Activity-based costing (ABC) techniques (Kee and Schmidt, 2000)

In general, design activities and associated methods were developed in the 1980's into the 1990's, and summarized in works like [8], Cooper [9], and Ulrich and Eppinger [12]. Research on quantitative tools and techniques became widespread in 1990's and are an active area of research as exemplified by ASME's Design and Technical Conferences[1]. This segment of academia continues to refine design techniques for automating design throughout the NPD process. Recently, there has been an increasing focus on the development of tools for the industrial design process. The hope is that these tools will make the process of design innovation more efficient and effective, resulting in new tools that can eventually be commercialized and used by mainstream practitioners. The provocative question we seek to ask is whether the migration to quantitative techniques is appropriate? Given the push for lower cost and improved time-to-market, are tools that require additional knowledge and effort on the part of the design team worthwhile to the practitioner? Is it appropriate to make the design process more complex, when the intent of the tools is to improve efficiency and effectiveness? What is the right balance between methods, tools and execution in a real-world setting? We argue that the process of design innovation, given an increasingly competitive and cost constrained landscape, needs to be hyper efficient – and effective, in execution. Firms, both nascent and established, will need to selectively adopt and adapt practices in the most proficient manner possible, thereby maximizing productivity while reducing the use of resources. Truncated and skeletal adoption of design practices has been observed as a predictor of successful outcomes in high technology new ventures – firms that are characterized by lack of resources and high-risk in new product development initiatives [30]. Stated formally:

Proposition 1: *Firms developing and commercializing new products and technologies will eschew onerous methods and quantitative tools for simplified, truncated innovation practices in order to improve NPD efficiency and effectiveness, using methods and tools only when necessary during the project.*

In order to investigate our proposition, we sought to investigate firms that would approximate state-of-the-art design innovation processes. Firms such as Continuum and IDEO are arguably world leaders in design thinking and execution [31]. These firms work on design strategy and product execution for products in nearly all industries and complexities. Below is a listing of design firms and products/technologies developed for clients.

Firm	Product Innovation
Continuum	P&G Swiffer
	One Laptop Per Child PC
	InSinkErator
	Insulet - Disposable Insulin Pump
Frog Design	HP SmartTouch PC
	Alltel CellTop Software
	SAP Enterprise Software UI
IDEO	Palm V PDA
	Dewalt Table Saw
	KwikPen Insulin Pen
M Design	Weber Q-Grill
	Thermoscan Thermometer
	BF Speaker System

Figure 2. Design firm and product map.

[1] http://www.asmeconferences.org/IDETC08/MechDesignComp.cfm

In large-scale development projects, design firms will engage clients and develop a saleable product from idea space to production support. During this process, they will proceed through phases as described in Figure 1. What is performed in those phases, and the methods and tools used, are the subject of this investigation. In the next section, we describe an empirical study of 44 design firms developing mechatronic products (products that comprise mechanical, electrical, and software elements[2]).

3 SURVEY OF DESIGN AND INNOVATION FIRMS

The sample was gathered with assistance of the Industrial Designers Society of America[3]. Given the contextual nature of NPD in the commercialization of innovative technologies and products, we argue that NPD is also contextual in design with unique differences between technologies and industries (e.g devices or biotechnology) [32]. That is why our focus here is on one context of NPD: multi-part mechatronic products. As such, the study was conducted only on firms that develop physical, multi-part mechatronic products. In all cases, a company employee was the main contact.

The main instrument of the study was a 30-question survey developed using Zoomerang,[4] and was administered as a confidential, electronic mail survey that was sent via blind carbon-copy. No incentives - financial or otherwise - were provided for completing the survey. The final sample consisted of 44 firms (a response rate of 68.3%). In checking early and late response bias, an ANOVA analysis was performed to check for differences based on when the survey was completed (see Chrisman, et al., [33]. No statistical differences between the early and late respondents were observed, suggesting that non-response bias was not a major problem [34].

Study Constraints and Controls

In the design of the study and data collection, type of firm (firms developing physical assembled mechatronic products) were constrained. The research only included firms that have the ability to design physical, multi-part assembled mechatronic products. Mechatronic products arguably demand the greatest level of NPD practice adoption because of the need for capabilities in design, cost engineering, manufacturing, and supply chain management. This is important if we are to accurately ascertain the level of methods and tools used during development. We argue that a simple consumer product will need less rigor than a complex device. Survey controls included the size of the firm and average experience of the development team.

Variables – Methods and Tools Used

NPD practices, methods, and tools were measured using a combination of Likert-type and custom ordinal scales. The work of Cooper [9],[10] was used as a basis for developing the questions and scales for teams, pre-development market planning, and phased development processes. We had several questions in our survey on each best practice to insure capture of latent data. For the best practices on structured brainstorming, digital design tools, cost engineering, and product platforms, there are few applied measures of application so we developed custom scales and measures. Descriptive statistics are shown in Table 2.

Table 2. Descriptive statistics of firms.

Description	Metric
Firm Size (no. of employees)	12
Average experience of employee (no. of years)	7.5
Use of a dedicated project manager (%)	81%
Average project duration (months)	18
Average project size ($)	$ 500,000.00
Use of a standard, structured NPD process (%)	9%

N = 44

[2] Definition: http://www.answers.com/topic/mechatronics

[3] The Industrial Designers Society of America (IDSA) is the voice of the industrial design profession, advancing the quality and positive impact of design.

[4] http://info.zoomerang.com/

The average size of the firms surveyed were 12 people, but the range of firm size varied from under 5 to over 100 employees. The average employee experience was 7.5 years, with some team members having great than twenty years of experience. Most of the firms, 81%, used a dedicated project manager. These project managers were also used as leaders in the structured brainstorming process. In terms of development duration, the average mechatronic project took 18 months from kickoff until completion. The most complex products in the study took 2 – 5 years to develop. The average development cost per project in the study was $500,000. However, 20% of the projects in the study cost over $1 Million in total development costs. Interestingly, only 9% of firms studied used the same, structured development process for each project. Most used a flexible and dynamic process that could be tailored to individual projects on an as needed basis.

The phase to tool map shown in Table 1 was used as a template to structure and analyze the data. In each column, percentages of use by the firms are described in Table 3.

Table 3. Survey results.

Phase	Firm Usage	Activity	Firm Usage	Method	Firm Usage	Quantitative Tools and Techniques	Firm Usage
Planning	100%	Perform market research	98%	Detailed competitive evaluation	40%	Product dissection	5%
		Define product portfolio	49%	Develop defined market segmentation	12%	Genetic Algorithm	0%
Concept Development	100%	Define project scope	100%	Structured brainstorming meetings	74%	Design synthesis techniques	0%
		Develop concepts	100%	Industrial design sketches and models	98%	Multi-criteria decision making	0%
		Concept selection	100%	Concept selection matrices	24%	Fuzzy decision models	0%
System-level Design	100%	Define subsystems and architecture	95%	Detailed layout of modular systems	12%	Design structure matrix	2%
		Develop final concept	100%	Industrial design concepts and models	100%	Genetic algorithms for design	0%
Detail Design	100%	M/ECAD	100%	Product design using 3D CAD software	100%	Automated CAD model construction	0%
		Prototype testing	100%	Physical testing and evaluation	98%	Finite Element Analysis	12%
		Kick-off tooling	85%	Evaluate sourcing options	72%	Cost and component evaluation modeling	0%
Production Ramp	95%	Product cost and margin analysis	89%	Detailed cost analysis and modeling	81%	Activity-based costing (ABC) techniques	17%

For each phase, the study firms approximated the development process as described in Figure 1, and were used by all firms in the study. Accordingly, the activities (e.g. market research) performed in each phase were equally used. Exceptions include defining a product platform-based portfolio early in the design process. This step was performed by 49% of the firms surveyed. Kicking-off production tooling was performed by 85% of firms, with the remaining 15% transferring that responsibility to the client. In performing cost and margin analysis, 89% performed that task during development, with the remaining firms again deferring that task to the client. In translating design activity to defined methods, the percentage of use by firms dropped off dramatically. For example, the use of defined market segmentation analysis was used by 12% of firms versus 49% that defined a product portfolio. Similarly, a detailed systems layout of modular architectures and interfaces was used by a similar percentage of firms (12%). Of those methods used heavily, design concepts, models, and prototypes were used by a high percentage of firms. During system-level and detailed design, CAD modelling and CAD-based prototypes were used by all firms (100%). Structured brainstorming, evaluation of sourcing options, and detailed cost analysis was performed by approximately 75% of the firms studied. In the translation of defined methods to the use of quantitative tools and techniques, our proposition was supported. Design firms overall do not use these tools. Only finite element analysis and activity-based costing techniques were used by a small percentage of firms.

In summation, firms are progressing through standard development phases, performing specific activities to foster development progress, and using some defined methods to complete those activities. Methods such as CAD and prototypes – essential to completion of a project – were used by all firms. Firms will use methods if they are critical to the project, if they are not – being niceties, not necessities – they will be less likely to be deployed. This intuitively makes sense, if firms are pressed for time and resources, they will select the critical path (passively or actively) towards completion – eschewing time draining analyses for quick results. According to Tom Merle, Vice President of Product Innovation at Continuum, "Implementing innovation processes and methods requires balance and judgment. You need to have a high-level framework that guides how innovation will progress and you need to be able to adapt the approach. Flexible teams are fast teams. Empowered teams figure out new ways to innovate and develop tools. Overly constrained teams fall into process mode. They think about check boxes, phase deliverables, and identified methods that may not be appropriate. You can't be too prescriptive and you can't be too loose. The balance is critical. We have seen great success by having a high-level understanding of a framework for development that is combined with an openness to allow teams to customize the exact approach." In the next section, a framework is proposed that illustrates how firms should keep development on the critical path, balancing activities, methods, and tools in order to maximize efficiency and effectiveness.

4 PROPOSED FRAMEWORK

The proposition of the article was supported, in that the state-of-the-art firms in terms of design innovation processes focus on rather simple NPD activities and methods, fully adopting methods and tools only when absolutely necessary. For example, CAD is ubiquitous, but FEA is only needed in certain situations. Rigorous quantitative methods such as genetic algorithms are seldom ever needed, if at all. This have ramifications for the development project, as firms will want to seek the critical path. Critical path methodology (CPM) has been in existence since the 1950's, and although firms may not be actively pursuing CPM [35], the data from the study indicates that firms will passively migrate towards critical path activities and methods in order to achieve efficient and effective outcomes. This notion is supported by literature, which notes that in design innovation, recent research has argued that rigorous processes can hurt the performance of novel new products [36]. There is certainly a need for balance in the strategic management in innovative firms (both new and established) between flexibility [37], structure, and process [38].

In developing a framework for firms, it is important that phases, activities, methods, and tools are illustrated, but going to deepest level of complexity is not desired. Only if necessary would quantitative tools be used, as these require additional resources and time. The firm needs to balance adoption of these tasks to foster increased development effectiveness and efficiency. Figure 3 illustrates the design process from idea to production, noting the different levels of project activity by color.

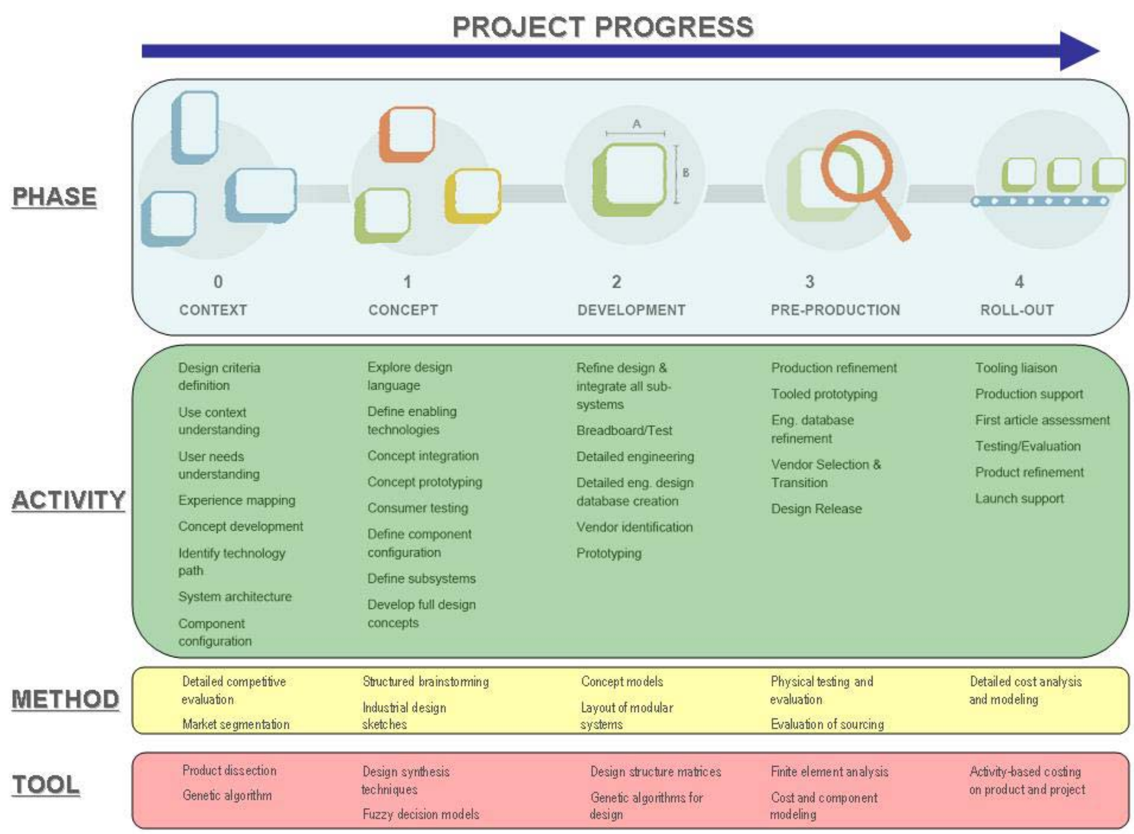

Figure 3. Detailed 'Green, Yellow, Red' development framework. Phase construct is courtesy of Continuum.

On the top of Figure 3 lists five phases, beginning with context of the project and progressing through roll-out. During the NPD project progress, activities are performed. These are highlighted in green, and include a list of specific items to be completed on the project. Most project operating time is spent completing these tasks. At the next level – yellow – methods are listed which support these activities. For example, industrial design sketches help explore project design language. Spending project time on methods is value added project time, but can increase costs as active man-hours are being spent to complete specific tasks. At the next level, quantitative tools and techniques can be used to support methods and activities when needed. In the case of design language, design synthesis techniques could be used if the project team believes those techniques would increase project effectiveness. Firms should note that time spent in the yellow and red regions can result in decreased efficiencies. For example, in the survey 50-60% of project costs were CAD design hours, time spent in the yellow region, active project value added time that is a necessity. If FEA is needed in the design to verify component performance, this drives the project further into the red zone, increasing the resources needed to complete the phase. The most efficient and effective firms will seek to spend minimal time in the yellow and red zones, seeking a critical path and restrained use of resources. Methods and tools can be used to increase project effectiveness, but firms need to balance those gains versus efficiency losses.

5 CONCLUSION

Design innovation is a challenging process, balancing the right combination of phases, activities, methods, and tools. In looking at 44 design firms, it is clear that these best-in-industry practitioners avoid onerous procedures and methods. Instead, they passively or actively seek a critical path in development to be as efficient and effective as possible. Only when needed, do they spend the extra time and resources to dive deeply into a problem and use quantitative tools such as FEA or rigorous activity-based cost analysis. In this paper, we proposed a framework that illustrates this deepening of project design tasks. Throughout the design process, the project should operate in the 'green' activity zone, progressing into the 'yellow' method zone to complete specific value added tasks, and venturing into the 'red' zone only when needed. In operating in the fashion, firms will tend to adopt practices only when and where needed, thereby balancing and improving efficiency and effectiveness.

As academics and practitioners, we need to be cautious in over complicating design innovation. While tools are important, automating each of the processes may be counterproductive, and not worthwhile to actual practitioners whose success in product development is tied to real dollars and sales. If research is dedicated towards methods and tools to automate the design process, they must be easy-to-use and integrate into the activities and methods of daily 'green zone' NPD. Tools that increase man-hours, and drain resources, will not be used. There needs to be a balance between usefulness and impact on the project. Academics should drive to have tools move from the 'red' zone, into the 'yellow' and 'green' zones where possible, decreasing complexity and increasing the chance that they will be utilized to increase innovation efficiency and effectiveness.

REFERENCES

[1] Urban, G. L. and J. R. Hauser, (1993). *Design and Marketing of New Products,* 2nd Edition. Prentice-Hall, Englewood Cliffs, N.J.

[2] Pahl, G. and Beitz, W., (1988). *Engineering Design: A Systematic Approach*, Springer, New York.

[3] Wheelwright, S. and Clark, K.B. (1992). *Revolutionizing Product Development*. The Free Press, New York.

[4] Boothroyd, G., Dewhurst, P. and Knight, W.A. (1994). *Product Design for Manufacturing and Assembly*, M. Dekker, New York.

[5] McGrath, M. E. (1995). *Product Strategy for High-Technology Companies*. Irwin Professional Publishing, New York.

[6] Otto, K.N. (1995). Measurement Methods for Product Evaluation. *Research in Engineering Design Theory Applied Concurrent Engineering* 7(2), pp. 86-101.

[7] Griffin, A. and Hauser, J.R. (1996). Integrating R&D and Marketing: A Review and Analysis of Literature. *Journal of Product Innovation Management* 13(3), pp. 191-215.

[8] Meyer, M.H. and Lehnerd, A. P. (1997). *The Power of Product Platforms*. The Free Press, New York.

[9] Cooper, R.G. (2001). *Winning at New Products*. Perseus Publishing, Cambridge, MA.

[10] Cooper, R.G. (2005). *Leadership: Pathways to Profitable Innovation*. 2nd Edition, Basic Books, New York.

[11] Krishnan, V. and Ulrich, K.T. (2001). Product Development Decisions: A Review of the Literature. *Management Science* 47(1), pp. 1-21.

[12] Ulrich, K. T. and Eppinger, S. D. (2004). *Product Design and Development*. 3rd Edition, Irwin McGraw-Hill, New York.

[13] Clausing, D. (1994). *Total Quality Development: A Step-by-Step Guide to World-Class Concurrent Engineering*. New York: ASME.

[14] Cagan, J. and Vogel, C.M. (2002), *Creating Breakthrough Products*. Prentice Hall, Upper Saddle River, NJ.

[15] Sutton, R.I. (2001). The Weird Rules of Creativity. Harvard Business Review, September, 95-103.

[16] Browning, T.R. (1997). An introduction to the use of design structure matrices for systems engineering, project management, and organization planning. *MIT Lean Aerospace Initiative*, Cambridge, MA, WP97-001-18.

[17] Altus, S.S., Kroo, I.M., and Gage, P.J. (1996). A genetic algorithm for scheduling and decomposition of multidisciplinary design problems, *Trans. ASME*, 118, pp. 486–489.

[18] Ogot, M. (2005). EMS Models: Adaptation of Engineering Design Black-box Modeling for Use in TRIZ, *Journal of TRIZ in Engineering Design,* **1**(1), pp. 27-39.

[19] Norman, D.A., (2002). *The Design of Everyday Things 2nd Edition*, Currency/Doubleday, New York, New York.

[20] Lojacono, G. and Zaccai, G. (2004). The Evolution of the Design-Inspired Enterprise. Sloan Management Review, 45, pp. 75-79.

[21] Kelly, T. (2001). *The Art of Innovation*. New York: Curreny.

[22] Rosenthal, S.R. and Capper, M. (2006). Ethnographies in the Front End: Designing for Enhanced Customer Experiences. *Journal of Product Innovation Management*, 23(3), pp. 215-237.

[23] Kumar, V. and Whitney, P. (2003). Faster, Deeper User Research, *Design Management Journal*, 14(2), pp. 50-55.

[24] Patnaik, D. and Becker, R. (1999). Needfinding: The Way and How of Uncovering People's Needs. *Design Management Journal*, 2, pp. 37-43.

[25] Levy, S. (2006). The Perfect Thing, *Wired Magazine*, November, pp. 136.

[26] Rao, P. (2006). Ive of the Apple, *Knight Ridder Tribune Business News*, Washington, pp. 1.

[27] Edwards, K.L. and Gordon, T.J. (1984) Characterization of Innovations Introduced on the U.S. Market in 1982, *U.S. Small Business Administration*, SB-6050-0A-82.

[28] Schumpeter, J.A. (1939). *Business Cycles*, McGraw-Hill, New York.

[29] Simpson, T.W., Maier, J.R.A., and Mistree, F. (2001). Product platform design: Method and application. *Research in Engineering Design 13(1)*, 2–22.

[30] Marion, T.J., (2008), "New Product Development Practices at Early-Stage Firms: A Pilot Study," *Academy of Management 2008 Annual Meeting*, paper 13663.

[31] Verganti, R. (2008). Design, Meetings, and Radical Innovation: A Metamodel and a Research Agenda, *Journal of Product Innovation Management*, 25, pp. 436-456.

[32] Balachandra, R., and Friar, J. (1997). Factors for Success in R&D Projects and New Product Innovation: A Contextual Framework. *IEEE Transactions on Engineering Management* 44(3), pp. 276-287.

[33] Chrisman, J.J., McMullan, E., and Hall, J. (2005). The influence of guided preparation on the long-term performance of new ventures. *Journal of Business Venturing* 20, pp. 769-791.

[34] Kanuk, L. and Berenson, C. (1975). Mail surveys and response rate: A literature review. *Journal of Marketing Research* 22, pp: 440-453.

[35] Meredith, J.R. and Mantel, S.J., Jr. (2006). *Project Management: A Managerial Approach*, Hoboken, NJ; John Wiley & Sons.

[36] Sethi, R. and Iqbal, Z., (2008). Stage-Gate Controls, Learning Failure, and Adverse Effect on Novel New Products. *Journal of Marketing* 72(1), pp. 118-134.

[37] Iansiti, M. (1995). Shooting the Rapids: Managing Product Development in a Turbulent Environment *California Management Review* 38(1), pp. 37-58.

[38] Song, M., Podoynitsyna, K., van der Bij, H., and Halman, J. (2008). Success Factors in New Ventures: A Meta-analysis. *Journal of Product Innovation Management* 25(1), pp 7-20.