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Innovation in a Requirement Life-Cycle Framework

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Abstract

In this paper, a requirements-based framework of innovation is discussed. Both customer and expert defined requirements are considered. The proposed framework treats requirements as evolving entities and is implemented using a data-driven approach. It provides a new perspective in support of the innovative product development process.

Keywords: *Innovation, requirements management, evolutionary computation, data mining.*

1. Introduction

The volume of information entering a corporate decision-making landscape is increasing. Not too long ago, corporate business models were based on information asymmetry, neglecting the customer needs. Customers did not have the full information about the products available to them. With the creation of internet, the information revolution was bound to happen. Nowadays, a customer can literally search any product available in the global market. This search is usually based on variety of requirements ranging from functional to emotional. Companies can not neglect analysis of customer needs. Therefore, the ability to successfully translating customer requirements in the product development process is of paramount importance, if not the most important one.

What is the best business model in today's competitive market? This is the question that constantly haunts business leaders who are at the front-end of competition as well as the research communities who are continuously developing the successful business model. Innovation, to be more precise, the ability to innovate, is on the top of the list (Christensen 1997, Schumpeter 1934). The ultimate goal of innovation is to satisfy customers. It can be done by envisioning the customer requirements, offering new value, or creating a new demand. This characteristic also highlights the difference of invention to innovation, as the former is laboratory-specific and the latter involves market success (Garcia and Calantone 2002).

Numerous research finding have recognized the importance of incorporating customer requirements into the innovation process (Ulwick 2002, Amara and Landry 2005). The link of transforming customer requirements to the innovation process, however, is not well addressed in the literature. The difficulty to establish such transformation process is

evident as the requirements itself are rather loosely defined and there are no widely-accepted quantitative metrics to measure them. Researchers have attempted to formulate frameworks to standardize this process. From a traditional process control perspective such frameworks are indeed helpful in synchronizing potential heterogeneous information and providing a common protocol for various stakeholders. It is not known how such metrics would facilitate innovation. An attempt to formalize the dynamics of innovation in a stringent way is much like trying to build a perfect model to predict the weather conditions.

This paper analyzes the relationships between requirements and innovation. The concept of Requirement Life-Cycle (RLC) is proposed. RLC views requirements as dynamic entities. The data-driven approach is proposed as an implementation methodology. Section 2 provides an overview on requirements and innovation. Section 3 discusses the proposed RLC framework. Section 4 concludes the paper.

2. Related Research

2.1 Requirements in Innovation

The Organization of Economic Cooperation and Development (OECD) defined innovation as "an iterative process initiated by the perception of a new market and/or new service opportunity for a technology based invention which lead to development, production, and marketing tasks striving for the commercial success of the invention" (OECD 1999). From this definition, it can be seen that innovation is an iterative process. The interactions among the determining factors in either internal or external environment of a company are not easily predictable as they may change over time (Stock *et al*. 2002). The goal of any innovation endeavor should be relatively stable as the process progresses. No company can allow unlimited resources consumption on any innovation project. After all, decisions are made under limited resources and knowledge and so does innovation.

Ulwick (2002) pointed out the mistakes that many companies made when they "listen to their customers". He believed companies should ask customers about what they want, not how they want. Customers may not be informed enough to come up with a good solution. Veryzer (1998) questioned the benefits of customer involvement in discontinuous innovation. Similar idea was also presented by Tidd (2001) who believed that customers are mostly likely to provide solutions to sustaining innovation, rather than disruptive innovation that has a much larger impact on the market. While Freel (2000) acknowledged that user-involvement has a positive impact on product design and development process, it is questionable if getting customer feedback during the development process is feasible.

Vogel *et al*. (2005) indicated the best way to read the future trend is by framing it in the context of the product users or other product stakeholders. Apple computer was not the first company to sell mp3 players, however, IPod has become a success. The reasons that IPod leads the mp3 player market are various but one obvious is the fact that it has addressed the user requirements. The basic functionality of mp3 player is simple, storing files in a portable device and playing music. However, the ability to incorporate the

emotional requirement makes the IPod an innovative product. With its intriguing design and user-friendly interface, a consumer connects with IPod that at times is has become a symbol of fashion. Capturing such requirements is not easy but the potential benefits are unprecedented.

2.2 Requirements Management

Requirements management or requirement engineering has its roots in software engineering as software designers attempt to capture the user requirements and implement them in the software. It includes the elicitation, understanding and representation of customer needs for a system (Some 2006). IEEE Standard 830: 1998 "Recommendation Practice for Software Requirements Specifications" is to facilitate software development process. In new product development (NPD), numerous techniques have been then proposed. Kerr *et al*. (2006) discussed the need for clear defined requirements for concurrent engineering. They proposed a system for automotive industry that can be used throughout the virtual enterprise consisting of OEM manufacturers and its suppliers. Lindgaard *et al*. (2006) integrated requirements engineering methodologies and user-centered design concept. In their case study, a cross functional team was formed to document the user requirements. The user analysis team faced the difficulty on the definition of a task and the level of detail in analysis of a task. Another branch of requirements studies adopt a case-based approach to analyze the requirements. Some (2006) proposed a restricted use case methodology to record the possible scenarios a user might encounter in the system. Seybold *et al*. (2006) developed a scenario-driven simulation model and took a car door control system as a case study.

Some of the requirement management literature adopts a process point of view based on the premise that all the potential scenarios can be incorporated in the system and designers or developers can easily search the state space and pick a feasible solution. In a well-formulated domain, this assumption might hold. From the innovation standpoint, user requirements are not easily captured, especially for those that are beyond the mundane ones. What makes an innovator different is the ability to grasp those implicit needs and transform them into technical requirements.
The impact of requirements on the innovation process is discussed in the next section.

3. The Flow of Requirements in Innovation

3.1 Requirements Life-Cycle

To better understand how requirements are used in the innovation process, it is necessary to consider at the Requirements Life-Cycle (RLC). The RLC can be broken in three phases, requirements identification, requirements diffusion, and requirements attainment (see Fig. 1). The RLC highlights the evolutionary nature of requirements. A requirement might change its form, merge with others, and be eliminated during the RLC. The reason that many traditional techniques developed to capture requirements are insufficient is because they do not stress this characteristic. As a result, many products that were designed to meet customer demands failed in the market.

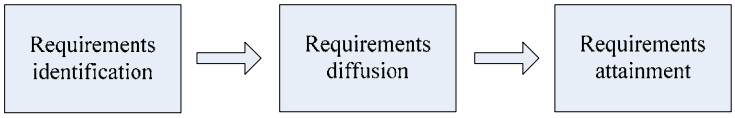

Figure 1. The requirements life-cycle.

3.1.1 Requirements Identification

To identify customer requirements, numerous market research techniques are increasingly used. Ulrich *et al*. (2000) discussed three common methods: interviews, focus group, and observing the product in use. These methods serve as direct measures to document the customer needs. Choosing the "right" users in such analysis is the most difficult part as different users might offer contradictory opinions. The problem exacerbates in the information age as many e-business companies only interact with their customers virtually, conducting face-to-face meetings with their customers is almost impossible. The advancement of database and web technologies, e.g., Google Analytics, facilitates the retrieval of customer requirements.

After retrieving the customer data, how to analyze the data becomes critical. Traditional statistical methods have been frequently used to analyze data, however, stringent assumptions of some models limit their applicability. In addition, nominal data can not be easily transformed to numerical ones and carry the implicit meaning at the same time. Data mining and evolutionary computation have created new possibilities for discovery of interesting patterns, trends, and associations from the data. A brief overview of the two disciplines is discussed next.

(1) Data mining

Data mining, an integral part in the process of knowledge discovery in database (KDD), is the process of generating useful information from raw data (Tan *et al.* 2005). Many successful applications in business, biosciences and engineering have been reported (Ganguly and Gupta 2004). It is an interdisciplinary field incorporating machine learning, artificial intelligence, and statistics. It is largely based on supervised learning and unsupervised learning. In supervised learning, a training data set with inputs and an output is used to build the learning function. In unsupervised learning the output class is not defined a priori. Classification and prediction fall under supervised learning, while clustering is widely used in unsupervised learning. Algorithms such as neural networks (NN), decision tree, support vector machine (SVM), and k-means clustering are widely applied. Readers interested in more details may refer to Tan *et al.* (2005) and Larose (2005).

(2) Evolutionary computation

Evolutionary computation covers the study of the foundations and applications of heuristics algorithms based on the principles of natural evolution. Examples of techniques include genetic programming algorithms and ant colony optimization (De Jong 2006). From the innovation perspective, the most promising innovative idea should be the "best-fit" for the market, similar to the concept of evolutionary

computation looking for the "best-fit" to the environment. The link between extracting requirements and evolutionary computation has not been built yet, however, there appear to be a natural match between the two.

3.1.2 Requirements Diffusion

The diffusion of customer requirements into the product development process is the essence of RLC. Fig. 2 shows the typical stakeholders in the product development process. Ambiguous customer requirements need to be converted to technical requirements but allow for flexibility in interpretation. For example, if the customer requirement is "a light car door", corresponding technical requirements may be the material type, the size of the door and so on. From an innovative perspective, the designers should perceive how the car door is used by customers and to find how this requirement appears. A sliding mechanism might completely satisfy such requirement.

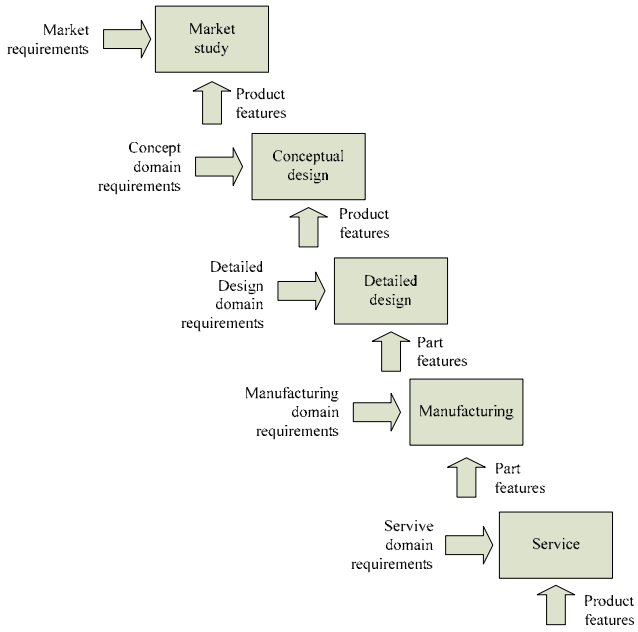

Figure 2. Requirements capture and diffusion in the product development process.

Widely known techniques such as Quality Function Deployment (QFD) and Design Structure Matrix (DSM) are widely used to match customer requirements with technical requirements that correspond to the technical specifications. Both methods utilize the matrix representation for pair-wise matching. Dong *et al*. (2001) proposed a variant of traditional DSM by initializing a design matrix (DM) first and then convert to DSM. A snapshot of a simplified QFD is illustrated in Table 1 and its variant is shown in Table 2. A customer requirement is matched with the technical ones. The existing format forces product designers to concentrate on the predefined interactions and could potentially curb innovative thinking. In the proposed requirement diffusion process the requirements are dynamic.

Table 1. A simplified quality function deployment table.

		Technical Requirements			
		Requirement a	Requirement b	Requirement c	Requirement d
Customer Requirements	Requirement A	**x**		**x**	
	Requirement B		**x**		**x**
	Requirement C		**x**	**x**	
	Requirement D	**x**			

Table 2. A variant of the QFD of Table 1.

		Technical Requirements			
		Requirement a	Requirement b	Requirement c	Requirement d
Customer Requirements	Requirement E	**x**		**x**	**x**
	Requirement B_1	**x**	**x**		**x**
	Requirement B_2		**x**		**x**
	Requirement D	**x**			

3.1.3 Requirements Attainment

The final phase of RLC is to see if the requirements have been indeed incorporated in the final product. It is often done when the product is introduced to the market. Successfully implementing the innovation-driving requirements into the product is critical but the ability to react to market response is of no less importance. The requirement attainment phase should provide feedback to the previous phases. Development process should be well-documented for comprehensive requirements analysis. Potential inefficiency may lie in the structure of the product development process rather than the requirements themselves.

4. Conclusion

Successfully transforming customer requirements into product characteristics is important in today's customer-driven market. It has been known for a number of years that product development process can not neglect the customer desires. Any innovative design should subscribe to the market requirements. The innovation-driving requirements are likely to be highly granular and may be generated by the customers as well as by experts along the product life-cycle. Capturing and maintaining such requirements has become a challenge in innovation. This paper stressed the importance of requirements in the innovation process. The proposed requirement life-cycle (RLC) concept is of evolutionary nature. The data-driven approach realizes this concept. The research discussed in this paper was focused on requirements flow rather than treating them as stationary entities. Empirical studies are needed to fully validate the proposed framework.

References

Amara, N. and Landry, R. (2005), Sources of information as determinants of novelty of innovation in manufacturing firms: Evidence from the 1999 Statistics Canada innovation survey, *Technovation*, Vol. 25, No. 3, pp. 245-259.

Christensen, C. (1997), *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard Business School Press, Boston.

De Jong, K.A. (2006), *Evolutionary Computation: A Unified Approach*, MIT Press, Cambridge, MA

Dong, Q. and Whitney, D. (2001), Designing a Requirement Driven Product Development Process, *Proceddings of 13th International Conference on Design Theory and Methodology, September 9-12, 2001, Pittsburgh, PA*

Freel, M. (2000), External linkages and product innovations in small manufacturing firms, *Entrepreneurship & Regional Development*, Vol. 12, No. 3, pp. 245-266.

Ganguly, A. R. And Gupta, A. (2004), Data mining technologies and decision supprot systems for business and scientific applications, *Encyclopeida of Data Warehousing and Mining*, Idea Group Publishing, Cambridge, MA.

Garcia, R. and Calantone, R. (2002), A critical look at technological innovation typology and innovativeness terminology: A literature review, *Journal of Product Innovation Management*, Vol. 19, No. 2, pp. 110-132.

Larose D. (2004), *Discovering Knowledge in Data: An Introduction to Data Mining*, Wiley, New York.

Lindgaard, G., Dillon, R., Trbovich, P., White, R., Fernandes, G., Lundahl, S., and Pinnamaneni, A. (2006), User Needs Analysis and requirements engineering: Theory and practice, *Interacting with Computers*, Vol. 18, pp. 47-70

Kerr, C.I.V., Roy, R., and Sackett, P.J. (2006), Requirements management: An enabler for concurrent engineering in automotive industry, *International Journal of Production Research*, Vol. 44, No. 9, pp. 1703-1717

Schumpeter, J. (1934), *The Theory of Economic Development*, Harvard University Press, Cambridge, MA.

Seybold C., Meier S., and Glinz, M. (2006), Scenario-driven modeling and validation of requirements models, *5th ICSE International Workshop on Scenarios and State Machines: Models, Algorithms and Tools*, Shanghai, May.

Some, S. (2006), Supporting use case based requirements engineering, *Information and Software Technology*, Vol. 48, No. 1 pp. 43-58

Stock, G.N, Noel P.G. and Fischer W.A. (2002), Firm size and dynamic technological innovation, *Technovation*, Vol. 22, No. 9, pp. 537-549.

Tan, P-N, Steinbach, M. and Kumar, V. (2005), *Introduciton to Data Mining*, Pearson Eduction, Boston, MA

Tidd, J. (2001), Innovation management in context: environment, organization and performance, *International Journal of Management Review*, Vol. 3, No. 3, pp. 169-183.

Ulwick, A.W. (2002), Turn Customer Input into Innovation, *Harvard Business Review*, January, Vol. 80, No. 1, pp. 91-97

Veryzer, R. (1998), Discontinuous innovation and the new product development process, *Journal of Product Innovation Management*, Vol. 15, No. 4, pp. 304-321.

Vogel, C.M., Cagan, J., Boatwright, P. (2005), *The Design of Things to Come*, Wharton School Publishing, Upper Saddle River, N.J.