Innovation and Technology Management

Joseph J. Simpson, The Boeing Company

Abstract. A systematic approach to innovation and technology management is outlined in terms of a generic systems engineering process. Two types of innovation, incremental and disruptive, are described and discussed. All aspects of the product development and application environment must be correctly managed if an organization wishes to consistently produce innovative technologies and products. System engineering concepts provide a structured framework for the successful practice of innovation and technology development, deployment and management.

OVERVIEW

Innovation and technology management is a key ingredient in any successful product management activity. Innovation is one of the basic components used to create a competitive advantage for an organization, and is considered a primary mechanism to ensure an organizations continued survival in a competitive business environment. Innovation and technology are defined in various ways in an organizational and management context. A text book definition of technology is "the skill, knowledge, experience, body of scientific knowledge, tools, machines, computers, and equipment that are used in the design, production, and distribution of goods and services." Innovation is defined as "the application of technological change to products and organizations." Christensen defines technology as "the processes by which an organization transforms labor, capital, materials, and information into products and services of a greater value." Christensen then defines innovation as "a change in technology." (Christensen)

New and innovative technology introduction is one of the primary factors driving the complexity of current business activities. Key aspects of innovation that will be discussed include; its value, its types, general contexts, and control. To facilitate the discussion of innovation and technology management, several general system types will be developed and defined in increasing levels of detail and abstraction. Three fundamental base systems are used to organize the concepts in this discussion, the environmental system, the product system and the organizational process system.

FUNDAMENTAL BASE SYSTEM DEVELOPMENT

Systems thinking and systems engineering are powerful intellectual and analytical tools that can be applied to the solution and management of complex problems. To facilitate the application of these tools to the area of technology and innovation management, three base systems are defined, those of the product, the organizational process system that makes the product, and the environmental system within which the product and organizations exist. These three base systems and their associated processes have been developed by Mar and Morias during their analysis of classical systems engineering management activities and practices and their development of the FRAT concept and process engine. (Mar and Morias; Mar) The FRAT concept has four parts: (1) anything can be viewed as a system, (2) a system is described by four views, (3) three systems must be considered simultaneously, product system, organizational process system, and the environment system and (4) the FRAT process engine is used to design and define the systems of interest. The relationship and interaction of these three general

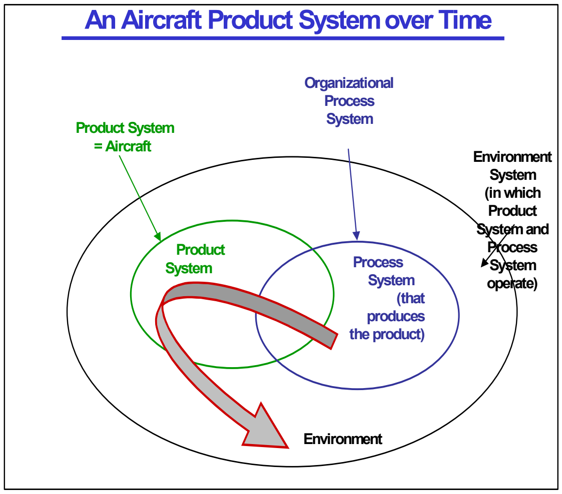

Figure 1 – Three General Systems

systems will be used to discuss the many aspects of management involvement in the process of innovation management within an organization. The organizational process system is the focus of most management activity involving planning, organizing, leading and controlling. The product system is designed, produced, and marketed by the organizational process system. Both of these systems exist in the general environmental system.

Using the FRAT model, each of these systems has a functional view, a requirements view, an architecture view and a test view. These four views provide a complete system description at any level of system abstraction. The functional view describes what the system must do. The requirements view describes how well the functions must be done. The architecture view details the mechanism that will perform the assigned function. The test view outlines the methods used to ensure that the selected architecture performs the assigned functions to the level stated by the requirements. In the context of these system models, organizational objectives are achieved by controlling the interfaces and interactions among the base systems and their subsystems.

ORGANIZATIONAL PROCESS SYSTEM INNOVATION MANAGEMENT

The organizational process system is composed of the four views outlined above, functions, requirements, architecture and test views. The functional view of the organizational process system details what the organizational system must do - its goals and objectives. The requirement view of the organizational process system states how well the functions, goals and objectives must be completed or satisfied. The architectural view details the organizational architecture that will be used to meet the goals and objectives. The test view outlines the techniques, metrics and methods that will be used to determine whether or not the selected architecture is meeting the stated

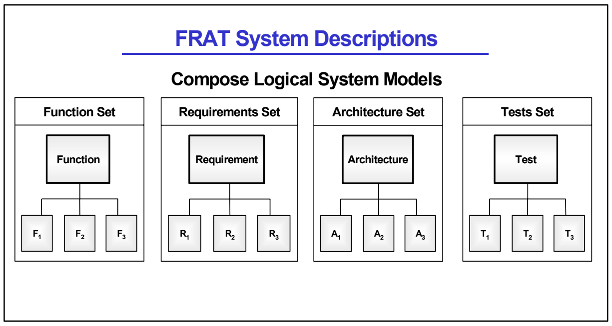

Figure 2 – FRAT System Views

organizational goals and objectives at the prescribed level. In most cases the test metrics for an organization are stock price, profit margin, and economic profit.

One of the basic management functions is forming an organizational hierarchy that will meet the goals and objectives at each level of organizational decomposition. From a practical point of view an organizational system is usually designed by function. Functional organizational types are used to group similar activities into their own lower level departments and groups. An organizations research and development department is an example of this type of functional alignment. Marketing, accounting, and manufacturing are further examples of organizational functions. The FRAT process engine, shown in Figure 3, is a generic process that can be used to define the functional departments in an organization, or define any system.

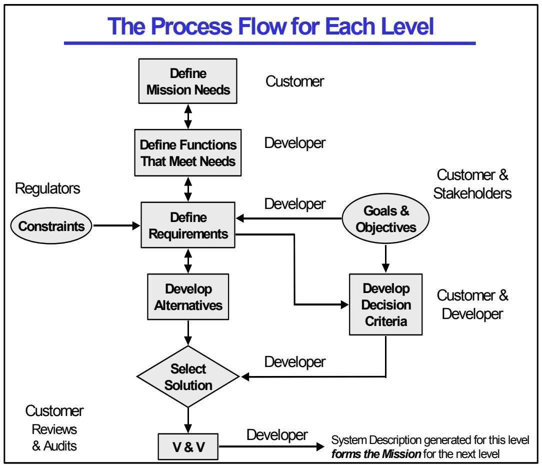

Figure 3 – FRAT Process Engine

The research and development function of an organization is discussed in the book, "The Smart Organization" by Davis and Jim Matheson. Challenges associated with creating value using strategic research and development are organized around four basic areas. These four areas are decision quality, best practices, principles and process. Based on consulting work with large, international companies, the authors outline and present a set of activities and practices that can be used to consistently create value using strategic research and development. Focused almost entirely on the research and development function of an organization, the authors build a logical "macro-process" that includes decision value development and a logical decision making process designed to guide the company in making strategic research and development decisions.

The decision quality concept is designed around six fundamental areas:

1- Appropriate frame
2- Creative, doable alternatives
3- Meaningful, reliable information
4- Clear values and tradeoffs
5- Logically correct reasoning
6- Commitment to action.

Management uses each of these areas, working together with other steps in the process, to provide the basic components for high quality decisions. A spider diagram, a circle with "six legs", is used to record each aspect of the decision. The spider diagram shape then becomes a visual metric used to measure the quality of each decision.

Each fundamental area has the following general characteristics and typical values.

1- An **appropriate decision frame** is important for every decision. Each decision and action can be viewed from several different perspectives or frames, selecting the proper frame highlights aspects of and adds information to the decision context. The proper decision frame is required to normalize values and analysis during the decision making process. Each decision type needs to be framed differently, short term tactical decisions will be framed much differently than long term strategic decisions.
2- A robust set of **creative doable alternatives** adds value to a decision. It is a clear indication that the current problem has been analyzed and considered from a number of perspectives. Creating this set of alternatives exercises the creative problem solving capabilities of an organization and provides a wide range of responses for the decision makers. When a wide range of creative ideas are used employees are encouraged to continue the creative process.
3- High quality decisions can only be made with **meaningful, reliable information**. The following several factors are important to consider when analyzing decision information; relevance to current situation, methods used to quantify uncertainty, lack of ambiguity and sources of uncertainty. When decision-making information is packaged and processed using these criteria, the resulting decision quality should be high.
4- A **clear set of values and tradeoffs** provides the operational basis for high quality decision making. The set of values that will be used in the decision making process must be well understood by all of the decision makers involved in the decision process. These values must be able to be normalized to one basic metric, like Net Present Value. After the alternatives have been ranked according to the selected value metrics, tradeoffs are used to evaluate areas of risk and time frames associated with the decision.
5- **Logically correct reasoning** assures an outcome based on facts and logical reasoning. Once the proper decision frame is set, and a robust set of alternatives have been developed - including values and tradeoff metrics, the other components of a high quality decision process are used in a well reasoned manner that generates an outcome based on facts and logical reasoning.
6- The final aspect of decision quality, **commitment to action**, is required to complete the decision process by assuring that the decision is implemented. The complete decision process is devalued if the decision is not implemented. In fact it represents wasted resources. If the decisions are never implemented it becomes difficult to engage people in the hard work necessary to make high quality decisions.

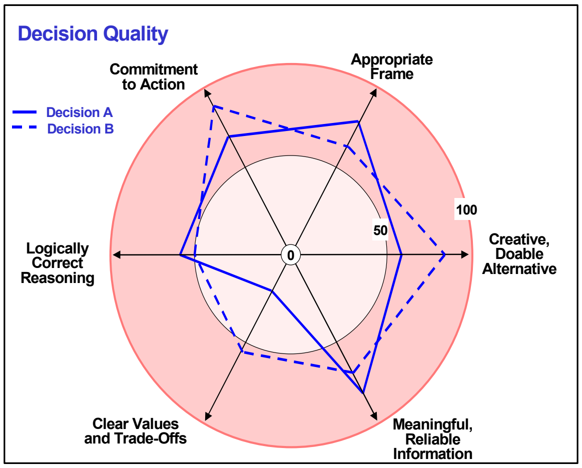

Figure 4 – Spider Diagram

Once the concepts of high quality decision making are understood and communicated through out the organization, these concepts should be instituted as organizational best practices and operational principles. In their research in strategic research and development decision making, Matheson and Matheson developed nine principles for research and development decision making. (Matheson and Matheson) These nine organizational principles are:

1- **Maintain a value creation culture**. Everyone in the organization understands that the primary focus of the group is creating value.
2- **Develop decision alternatives**. Multiple alternatives must be developed and

analyzed to provide a range of decision choices.

3- **Commitment to continual learning**. Everything changes, value must be created in full recognition and understanding of this continual change process.
4- **Embrace uncertainty**. The organization must know how to quantify and deal with uncertainty in their processes and products.
5- **Maintain an outside-in perspective**. Strategic long-term value creation must take the external environment into consideration as it relates to the specific area of the current decision.
6- **Use systems thinking**. Development of strategic value by creating products and services impacts many areas. Systems thinking is used to analyze and understand the long term impacts of the strategic decision.
7- **Ensure open information flow**. Open information flow is required to focus all of the organizational resources on the decision at hand.
8- **Achieve alignment and empowerment**. An organization must provide mechanisms that allow wide participation in the decision making process with people empowered to take the actions required to create value in the current situation.
9- **Institute disciplined decision-making**. An organization must have a process by which they systematically produce high quality decisions. This process must be continuously improved to create a habit of high quality decisions.

Once an organization has instituted these nine principles it will allow them to successfully implement and maintain the best practices required for high quality decision making. While most of their work is focused on the organizational process of decision-making and value creation, the activities do include decisions that affect the product system. The product system is the product the organization exchanges with the external environment to create value for both the organization and their customers.

PRODUCT SYSTEM INNOVATION MANAGEMENT

While the Mathesons focused their discussion on the organizational system *elements of decision making* with regard to innovation and technology management, Christensen focused his research on the *elements directly associated with product system* innovation and technology management. (Christensen) In "The Innovator's Dilemma" Christensen discusses his research in the companies involved in the computer disk drive industry, the steel milling and production industry and the mechanical excavator industry. Christensen outlines the specific types of new technology that were incorporated into products and the associated values and decisions that companies used when evaluating these new technologies. Two general types of product system innovation technologies are detailed, sustaining technologies and disruptive technologies. Sustaining technologies are technologies that are successfully incorporated into existing product applications by the current industry leading companies. Disruptive technologies are technologies that are not incorporated by the current industry leading companies. These technologies were identified as the primary factor driving the failure of many well-managed technology companies. Outstanding companies that

1 - Did everything right,
2 – Used the techniques detailed by the Mathesons,
3- Placed large investments in strategic research and development,
4- Listened to their customers, and
5- Were in tune with the current market competition

still lost market leadership when they encountered disruptive technology and market changes.

Market-leading industrial companies exist in an environmental system that includes their customers and their suppliers. The suppliers and customers are organized into supply networks and value networks. Value networks are introduced here to reinforce the idea that many companies and supply chains are designed to reflect the product system architecture. In this way the current product system architecture reflects not only the architecture that provides value to the customer, but also gains organizational political power and market economic value. The primary focus of private companies is creating an increasing volume of profit from its product stream. This focus creates an underlying bias for large profit and market growth increases in almost all business decisions. For example, in the aircraft industry, it is more efficient to have a family of aircraft that all share similar hardware parts and all have similar cockpit functions. If an aircraft company has existing aircraft designs, customers, facilities, and factories that produce aircraft that do not have these common characteristics, it is very costly to redesign the product line to gain efficiency from product commonality. If another aircraft company has designed all of its aircraft and production facilities to incorporate common functional characteristics then this aircraft company may be able to provide greater long term value to their customers than other aircraft companies.

The dynamics of disruptive technologies are examined by reviewing the history of the mechanical excavator industry. The mechanical excavator industry has gone through three major technology revolutions. Two were in the sustaining technology category and the other was a disruptive technology. The two sustaining technologies were sources of power for the equipment: (1) gasoline powered engines instead of steam and (2) diesel engines and electric motors instead of gasoline motors. In both of these technology innovation cases the leading equipment companies were the leaders in developing and deploying these technologies. The third technology, hydraulic actuated shovels, was a disruptive technology. Only four of the companies that provided equipment prior to the introduction of hydraulics were still in business when the hydraulic technology had taken over all of the established excavation equipment business.

Key characteristics of the hydraulic disruptive technology introduction were also found in the computer disk drive business. The key characteristics are a combination of factors including company market share, expected profit margin, technology maturity, technology customers, and technology application. When hydraulic excavators were first introduced, their capacity and productivity was not as good as the existing cable operated excavating machines. As a result, the major excavation contractors did not want this type of machine, and the established equipment manufactures did not build this type of equipment. The first market for hydraulic excavators were small contractors. New small companies were started to provide this type of excavation equipment to this market segment. The first hydraulic excavators had limited reach, power and bucket capacity. However, once companies were able to make a profit selling these limited function excavators to a new market segment, they turned their attention to increasing the function of the hydraulic excavator enough to take a small market segment away from the established cable-operated excavator equipment production companies. This is a key aspect of a disruptive technology. The technology first starts with a new set of customers using the technology or products that incorporate the new technology. Once this market segment is established and profitable with the new customers, the disruptive technology companies focus on taking more and more market share from the established technology providers. They do this by incrementally increasing the usefulness and value of the products that incorporate the disruptive technology. Each time this happens the new entrants into the market get stronger and make more profit at the expense of the established companies. The established companies do not usually introduce the disruptive technology because that is not the type of technology and capability being used by their customers. As the disruptive technology develops, more of the market share is taken by the disruptive technology and it becomes more expensive for an established firm to retool to introduce the disruptive technology in their products and services.

Company-size and market-size are other key factors in the success of disruptive technologies. The profit generated by the market when it is first addressed by a disruptive technology is not enough to motivate an established company with a large organization and an aggressive profit improvement plan to enter the new disruptive technology market. These market segments are left for smaller companies to develop. The steel industry and the introduction of a disruptive technology that allowed “mimi-steel mills” to compete in the market place and eventually take significant market share from established large steel mills is also covered by Christensen.

In the computer disk drive industry many examples of disruptive technology introduction can be found. Most cases of disruptive technology in computer disk drive area are centered around the factors of disk size and storage capacity. True to the disruptive technology pattern, each of these disruptive technologies provided less capability than that demanded by the current established, dominant market segment. However, small new market segments were found that supported the introduction and profitable development of these disruptive technologies. In every case these new technologies displaced the established storage hardware. Christensen points out that in many if not all cases the technology was available to and produced by the market leading firms. However, the market leading firms did not have management values, supply chain, value chain and customers that could make the disruptive technology profitable. This fact highlights the necessity of matching the disruptive technology with an organization of the proper size and motivation to make it successful under the initial market conditions. This fact suggests a strong tie between the product system design and the organizational process system design. This connection must be used to balance the organization and product systems to achieve success in the disruptive technology area.

ENVIRONMENT SYSTEM INNOVATION MANAGEMENT

The established technology markets and the potential markets for disruptive technologies exist in the general environment system. Sustaining technology innovation is based on market research, market development and market forecasting activities performed by the marketing function in the organizational process system. However, the markets for disruptive technologies are unknown and unknowable at the time of the technology development. Therefore, managers involved with the development, production and marketing of disruptive technology products must fully engage the external environment seeking out new markets and applications for the disruptive technology.

Christensen details market examples in the motorcycle, disk drive and microprocessor industries that illustrate the difference between sustaining technology marketing and disruptive technology marketing. Disruptive technology's initial characteristics of poor performance in the established market and no well-defined initial market present a unique marketing problem. In its initial stages, managers must distribute the technology and observe how it is used. This is an initial learning process not only for the organizational system but also for the market segment in the environmental system. Working and learning together, managers and customers define the initial emerging market for the disruptive technology.

NEW TECHNOLOGY DEVELOPMENT AND INNOVATION MANAGEMENT

Innovative technologies can be developed and applied in many areas - in the organizational process system, in the product system and in the environment system. However, most companies focus on developing innovative technologies for direct incorporation into their current or future products. The role of new technology development in new product development was researched and reported by Sampathkumar, Clausing, Schultz and Fricke. (Sampathkumar, Clausing, Schultz and Fricke) In this analysis of technology innovation, the development of the product system and the development of new technology are clearly separated and discussed. A new product can be developed by taking an existing product and using the product in a new application or a new product can be developed by taking an existing product and incorporating new technology into the product that is still used in the same type of applications.
This discussion is framed by assuming there are three independent, concurrent incremental development activities taking place. These three concurrent activities are: (1)incremental development of new technology, (2) incremental development of technology applications and lastly (3) incremental development of product systems.

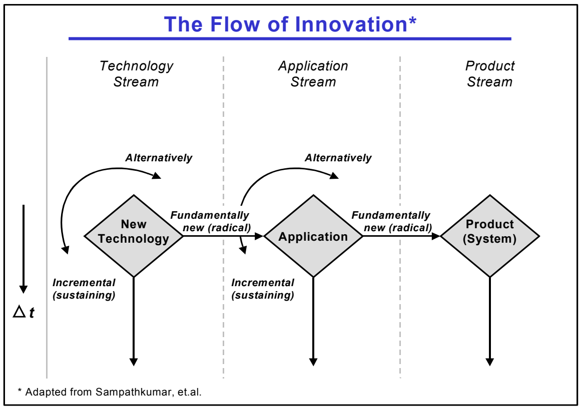

Figure 5 – Innovation Flow

Fundamentally new or radical technology innovation is required as an input to the technology application incremental development process. This introduction of innovative technology can either be used to continue the incremental development of the technology application activity, or to spawn a fundamentally new, or radical, application innovation (which is then used as an input into the product development process). This radical technology application innovation can then be used to continue the incremental product development process. However, if the radical technology application suggests a fundamentally new or radical product development process, a highly integrated technology application and product development process is required to successfully develop this radically new product.

To assist in determining when this special type of product development mode is required, Sampathkumar developed a set on measures for "newness." "Newness" measures were developed for both new technology and new technology application areas. The metrics used to distinguish technology "newness" are:

1- Functional structure and logic. This metric addresses how much the new technologies functional structure and logic depart from known technologies.
2- Physics used to implement the function(s). This metric measures the difference in the physics used to implement the new technology and the physics used to implement known technologies.

If the technologies functional structure and the physics used to implement the new structure are different from known technologies then the technology is determined to be radically new. The value of the specific technology "newness" metric is determined by the technology managers developing the new technology. Another set of "newness" metrics was developed for the technology application area. The metrics values are determined by the application "end-users." The application metrics are:

1- Unanticipated benefits. This metric is a measure of the degree to which the application fills unanticipated, unknown, and/or unmet technology needs.
2- Required amount of learning or operational change. This metric measures the amount of learning or operational change required to use the new technology application.

If the unanticipated benefits and required amount of learning for the technology applications are different than similar technology applications, the end users will consider this a radically new technology application. These user metrics are matched with a "primary main function (PMF) performance" metric that is used by the technical managers to evaluate the new technology applications impact. The metric is a measure of how different this technologies PMF is from similar technology applications. If both the technology used to perform the PMF and the performance of the PMF is different, then this is deemed a radically new technology application.

A SYSTEMATIC VIEW OF INNOVATION AND TECHNOLOGY MANAGEMENT

As outlined in this paper, innovation and technology management impacts almost every area in modern business practice. While the Mathesons focused on the communication and decision principles and processes needed for a successful research and development activity, Christensen focused of the aspects of product development that created disruptive technologies and gave some companies great advantages in certain technology areas. Sampathkumar defined metrics that can be used to determine if a technology is radical or just sustaining in its development and its impact on applications that use the technology.

It is clear that radical and disruptive technologies give substantive market advantage to the companies that develop, produce and successfully market products based on these types of technologies. However, to fully understand the forces that make disruptive technologies a powerful economic force, one has to have an understanding of the product system, the organizational process system and the environment system that are associated with the new technology application. The FRAT system model was introduced and used to organize and present a framework for discussing the complex factors associated with technology and product innovation. To successfully deal with disruptive technologies organizations must not only analyze the technology but also the current technology application market and their current organizational structure and culture.

In many cases an organization must create a new group to manage and develop the new disruptive technology. Often the current organization that is involved in incremental technology and product development does not have the proper skills, culture and motivation to be successful with a radically new technology. From the literature reviewed for this paper, it is clear that there are few if any common standards for measuring the amount of innovation in any given technology or technology application. Standard metrics for this type of technology innovation measurement is required before data in this area can be collected and compared in any realistic fashion.

The FRAT system view provides a mechanism to establish and apply a common metric set and a common framework for discussing these types of technology innovation and management tasks and organizational interactions. The establishment and analysis of the three basic systems (product system, organizational system, and environment system) by the FRAT process engine assures that these interacting areas will be considered during the system of interest development. Further, working together, the FRAT concepts and process engine provide a structured, generic approach to the management of innovation and technology. As the generic process is applied to a specific area more structured and useful information is developed and used to continue the detailed systems design. The interaction of the three general systems is used as a guide to assure that all aspects of the problem are being addressed.

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BIOGRAPHY

Joseph J. Simpson. Joseph J. Simpson’s interests are centered in the area of complex systems including system description, design, control and management. Joseph has professional experience in several domain areas including environmental restoration, commercial aerospace and information systems. At Westinghouse Hanford Company, Joseph was responsible for the conceptual and preliminary design of a requirements management and assured compliance system. Mr. Simpson developed a successful research proposal to NASA Langley on “Meta-Semantics and Object Models for Engineering Management” while working for the Boeing Company in 1999. While working in the internet domain, Joseph developed and deployed test-bed software essential to a major web-based commercial product. Mr. Simpson returned to the Boeing Company in 2001 where he is currently involved in work on the B2 program.

Joseph Simpson has a BSCE and MSCE from the University of Washington and is currently enrolled in a systems engineering masters program at the University of Missouri at Rolla. Joseph is a member of INCOSE , ACM, and IEEE, and has obtained various information and computer system certifications.