Managing Innovation and Change Processes: Findings from the Minnesota Innovation Research Program*

Roger Schroeder
Andrew Van de Ven
Gary Scudder
Douglas Polley

This article describes how innovations develop over time based on findings emerging from seven innovations included in the Minnesota Innovation Research Program. These observations are very different from typical models in the literature of the innovation process. The actual process is fluid, and includes an initial shock to propel the innovation into being, proliferation of the original idea, setbacks and surprises along the way which provide numerous opportunities for learning and failure, and a blending of the old and the new as the innovation is implemented and diffused. This article is one small step in developing descriptively more accurate and useful models of the innovation process based on longitudinal research studies.

INTRODUCTION

Studies of organizational and technological innovation tend to focus on two basic types of questions:

(1) What are the antecedants (facilitators/inhibitors) to or consequences (outcomes) of innovation in a given setting?

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Andrew Van de Ven is 3M Professor of Human Systems Management, Roger Schroeder and Gary Scudder are Professor and Assistant Professor, respectively, of Management Sciences, and Douglas Polley is a doctoral student in Strategic Management and Organization—all in the School of Management at the University of Minnesota.

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(2) How do innovations emerge, develop, grow, or terminate over time?

Although many studies of innovation have focused on the first question (see, e.g., Tornatsky et al.[1]) very few have examined the second question. Typically, the first question is addressed by the researcher developing a measure of the degree of innovativeness in a given setting, and then either analyzing the percentage of variation in innovativeness that is explained by a set of independent factors, or by determining if innovativeness is related to some outcome criteria. While these "variance theory" studies can provide useful knowledge of the causes or consequences of innovativeness, they do not provide an understanding of the second question, which requires a "process theory."[2] Relatively little attention has been given by scholars to describing the processes by which organizational and technological innovations actually develop and are implemented over time. Even less attention has been given to developing process theories which explain how and why innovations develop and either become successes or failures on the basis of the probabilistic arrangements of discrete states of events over time.[2] Yet an appreciation of the temporal sequence of activities that occur in developing and implementing new ideas is fundamental to the management of innovation.

The purpose of this article is to address this paucity of knowledge by developing observations about the process of innovation that emerge from comparing the developmental patterns of seven innovations now being studied over time in the Minnesota Innovation Research Program.* The seven innovations include four new product technologies (hybrid wheat, cochlear implants, therapeutic apheresis, and a naval weapons system) and three new administrative arrangements (a new business startup, site-based management of public schools, and strategic human resources management).

Part I of this paper provides a conceptual introduction by reviewing existing literature on innovation process models, which guided the initial development of this research. However, as the longitudinal case studies progressed, we found existing process models increasingly unsatisfactory in being able to explain the developmental patterns we observed in the seven cases. This led us to adopt a grounded theory[3] approach to the research, and to develop and present in Part II a set of six observations that appear to capture significant process patterns in the development of the seven innovations. Finally, in Part III we examine the conceptual links between the six observations, and outline the rudimentary ideas for developing a new process model for describing the innovation process that differs in several fundamental respects from existing models in the literature.

PART I: CONCEPTUAL OVERVIEW OF INNOVATION PROCESS MODELS

While invention is the creation of a new idea, typically innovation is defined in a more encompassing sense as the development and implementation of a new idea—be it a new technology, product, organizational process, or arrange-

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ment.[4-7] It follows that the process of innovation is the temporal sequence of activities that occur over time in developing and implementing new ideas. Table I illustrates the basic developmental phases or stages that have been typically proposed by management scholars to describe innovation and change processes at the individual, group, organizational, and societal levels of analysis. Three issues stand out when assessing the process models listed in Table I.

First, most innovation process models available in the literature are derived or borrowed from process models of either: individual or group decision making,[8-12] small group development,[13,14] organizational change and development,[15-17] or organizational planning.[18-20] To be sure, models have also been proposed for the innovation process itself. For example, there is Utterback and Abernathy's[21] model of joint process and product innovation, Usher's[22] cumulative synthesis theory, and a host of innovation diffusion process models reviewed by Rogers.[5] However, as Table I illustrates, there is a striking similarity between these innovation process models and those proposed for individual decision making and group and organizational development. A basic unresolved question is whether the process of innovation is unique or a common "cousin" to processes of individual, group, and organizational change.

Second, with the exception of Cohen, March, and Olsen,[10] the most common feature in these models in Table I is that they propose a simple unitary progression of phases or stages of development over time. For example, the innovation process has traditionally been viewed as a sequence of separable functional stages (e.g., design, production, and marketing) sequentially ordered in time and linked with transition routines to make adjustments between stages. These simple unitary stage-wise progression models are increasingly being discredited because of their lack of empirical validity or correctness. Moreover, when researchers use a priori stages or phases to design their research and collect data, their results can quite easily become self-fulfilling prophesies.[23,24] A growing body of evidence suggests that organizational innovation and change processes are considerably more complex than the stage-wise models in Table I suggest.

This evidence warrants a reexamination of previous developmental models in terms of questioning whether organizational or technological innovation proceeds in a discrete, consecutive series of phases or stages. In particular, Van den Daele[25,26] points out that a single-sequence model of development is simply inadequate to deal with the complexities of change and innovation processes because it assumes invariance between and within all units in following a prescribed order of developmental phases, one locked in step after another. Van den Daele[25] proposes a more realistic typology of developmental models that go beyond simple unitary progression, and includes multiple, cumulative, and conjunctive progressions of convergent, parallel, and divergent streams of activity sequences that may unfold as an innovation develops over time.

A third striking issue about most process models of innovation and change in the literature is that they are normative prescriptions without adequate empirical evidence to substantiate their validity. With the exception of retrospective case histories of organizational innovations, very little longitudinal empirical study has been conducted to evaluate these process models. Very few studies have supplemented case histories with real-time observations of the innovation process while it is occurring. Of the historical studies that have been conducted, most were conducted after the outcomes of the innovation were known. It is widely recognized that knowledge of success or failure invariably bias a study's findings. Thus,

Table I. Comparisons of Developmental Phases in Process Models.

Authors and Summaries	Beginning	Activity Phases			End
Group Development Models					
Lewin[13] Social Psychological Description of Change Process in Individuals and Small Groups	1. Unfreezing -Recognition of a need -Willingness to give up	2. Moving -Activities Undertaken to Design and Implement a Change			3. Freezing -Institutionalizing New Behavior
Bales and Strodtbeck[14] Observations of Phases in Group Decision Process (8 Cases)	1. Orientation -Address Problem in Cognitive Terms without Committing	2. Evaluation -Speaking in Evaluative Terms			3. Control -Attempts to Control by Joint Action
Decision Process Models					
March and Simon[8] Description of Administrative Problem Solving with Bounded Rationality Conditions	1. Parenthood of Invention is Necessity, Opportunity, and Moderate Stress	2. Intelligence -Problem Formulation	3. Design -Search, Screen & Evaluate Alternatives	Factor design –elements into substantive programs	4. Choice -Decision to Implement Satisfactory Solution
Mintzberg et al.[9] Field Study of 25 Strategic, Unstructured Decision Processes	1. Identification Phase -Decision Recognition Routine -Diagnosis Routine	2. Developmental Phase -Search Routine -Design Routine			3. Selection Phase -Screen Routine -Evaluation–Choice Routine -Authorization Routine
Cohen, March, and Olsen[10] Model of Organized Anarchies Based on Universities Study	Decisions are Outcomes of Relatively Independent Streams within Organizations. -Stream of Choices -Stream of Problems -Stream of Energy from Participants -Rate of Flow of Solutions				
Quinn[12] Case Studies of Nine Major Corporations	Fourteen Process Stages Beginning with Need Sensing and Leading to Commitment and Control Systems. Flow is Generally in Sequence but may not be Orderly or Descrete. 1. Sense Need	2. Develop Awareness & Understanding	3. Develop Partial Solutions	4. Increase Support	5. Build Consensus 6. Formal Commitment

Organizational Planning Models						
Friedmann[18] Normative Model of Innovative Planning for "Retracking American" Institutions and Communities	1. Identify & Describe Problem as Collective Phenomenon	2. Identify & Describe Patterns of Collective Behavior	3. Identify & Involve Institutions Responsible for Behavior	4. Analyze & Relate Performance of Institutions to the Problems	5. Formulate Proposal for Structural Innovation in Response to Problem	6. Implement Strategy and Make Adjustments on an Ongoing Basis as Necessary in the Course of Action
Ackoff[19] Normative Model of "Interactive Planning" for Designing Idealized Futures of Social Systems	1. Ends Planning -Design Idealized Future Goals that are Technologically Feasible	2. Means Planning -Invent Alternative Courses of Action	3. Resource Planning -Determine Type, Amount and Sources of Resources Needed	4. Organizational Planning -Determine and Design Organizational Arrangements Needed for plan.	5. Implementation & Control Planning -Implement, Control, Evaluate, and Improve Plan under Changing Internal and External Conditions	
Delbecq and Van de Ven[20] Normative Model of Program Planning & Evaluation Process for Groups, Organizations, and Communities	1. Prerequisites -Identify Complexity of Problem or Goal to be Dealt with	2. Problem Exploration -Involve Users to Identify Needed Priorities	3. Knowledge Exploration -Involve Experts to Reconceptualize Problems & Identify Solutions	4. Program Design -Involve Affected Parties in Developing New Program Proposal & Implementation Plan	5. Program Activation & Evaluation -Trial Implementation and Formative Evaluation of New Program	6. Program Operation & Diffusion -Institutionalize Program as ongoing Activity and/or Transfer Program to Adopters
Lorange[20] Normative Model of Corporate Strategic Planning	1. Objective Setting -Identify Relevant Strategic Alternatives	2. Strategic Programming -Development of Programs for Achieving Chosen Objectives	3. Budgeting -Establish Detailed Action Program for Near-term	4. Monitoring -Measure Progress toward Achieving Strategies	5. Rewards -Establish Incentives to Motivate Goal Achievement	
Organizational Change and Development Models						
Lippet, Watson, and Westley[15] Normative Model from Cases of Org. Change	1. Develop Need for Change	2. Establish Relation with Change	3. Diagnose Problem of Client	4. Examine Alternatives and Establish Goals and Action Routes	5. Transform Intentions into Change Efforts	6. Generalize & Stabilize Change	7. Terminate Relation with Change Agent

Table I. Comparisons of Developmental Phases in Process Models—*Continued*

Authors and Summaries	Beginning	Activity Phases				End
Dalton, Lawrence, and Greiner[16] Normative Model of Change Process Developed from Case Studies of Large-Scale Organizational Changes	1. Pressure on Top Management	2. Intervention from Outside & Reorientation	3. Diagnoses & Recognition of Problems and Their Determinants by Gathering Information at all Levels of Organization	4. Invention of Solution & Obtain Commitment to Change through Participation	5. Experiment with Solution & Search for Results	6. Reinforce New Practices with Rewards & Feedback
Hage and Aiken[17] Description of Program Change Process Within	1. Evaluation -Organizational Elite Identify Need for Change and Consider Alternative Means		2. Initiation -Elite Choose Solution and Search for Them	3. Implementation -Start of New Activity		4. Routinization -Stabilize Program Change
Innovation Process Models						
Usher[22] Normative Model of Innovation Emergence	1. Perception of the Problem -Recognition of Partial or Incomplete Need Satisfaction		2. Setting the Stage -Elements Necessary for Solution are Brought Together	3. Act of Insight -Essential Solution is Found		4. Critical Revision -New Relations Become Understood and Worked into Context
Abernathy and Utterback[21] Model for Process and Product Innovation Based on 120 Firms in Five Industries	Product Development 1. Performance Maximizing -Rapid Product Change Emphasizing Unique Product and Performance Process Development 1. Uncoordinated -Process Largely Unstandardized and Manual		2. Sales-maximizing -Reduced Uncertainty Some Designs Dominate 2. Segmental -Production Systems Become Mechanistic and Rigid		3. Cost-minimizing -Product Variety Reduced Product Change Coupled with Process 3. Systemic -Large Integrated Process Tightly Coupled Process Elements	
Rogers[5] On the Development & Diffusion of Innovation	1. Need -Recognition of Problem or Need	2. Research -Application of Knowledge to Problem	3. Development -Idea into Useful Form	4. Commercialization -Manufacturing, Packaging, Marketing, & Distribution of Product or Process	5. Diffusion & -Adoption of Innovation	6. Consequences -of Innovation

while historical analysis is necessary for examining many questions about the innovation process, it is generally better, if possible, to initiate historical study before the outcomes of an innovation or change process become known. In addition, we can obtain a richer and less biased description of the complexities of the process by using multiple longitudinal research methods.

We conclude that the body of knowledge about innovation processes in the literature is highly equivocal and suspect, particularly in terms of the three basic problems mentioned above (whether innovation is unique from other organizational processes, widespread acceptance of developmental stages, and little empirical evidence—largely limited to retrospective case histories—to substantiate the innovation process models which are largely prescriptive in nature.) The present research was undertaken with the aim of avoiding these problems, and hopefully making a contribution that partially corrects these problems. Specifically, as will be discussed in the next section, efforts were made to avoid these problems by undertaking a longitudinal study that tracks the development of a variety of innovations over time, and by using a grounded theory approach[3] to identify the developmental processes actually followed in each innovation instead of entering into the research with a particular process model in mind. Such an inductive approach has recently been suggested by Lewin and Minton[27] as useful and needed in order to begin to appreciate the complexity and "messiness" of organizational processes.

The Minnesota Innovation Research Program

This research is part of a major longitudinal research program on the management of innovation being undertaken by investigators at the University of Minnesota. As Figure 1 illustrates, the research, now in its fourth year, longitudinally examines the development of a wide variety of innovations in terms of five key concepts: ideas, people, transactions, context, and outcomes. Since the research framework

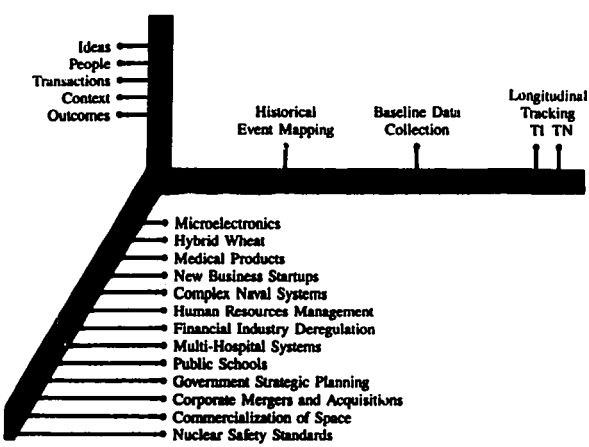

Figure 1. Innovation Research Program.

has been described elsewhere,[6] it will only be summarized briefly here. The research program examines the innovation process by tracking the development and implementation of new ideas which are carried by people who, over time, engage in transactions or relationships with others within a changing institutional context. Significant changes in these factors (ideas, people, transactions, context, and outcomes) represent an event. A systematic mapping of events over time has been the central task for all studies in the innovation research program.

Multiple methods are being used to conduct the longitudinal study of each innovation. First, historical case studies were written based on interviews and archival information about significant developments in the innovative ideas, people involved, transactions or relationships they engaged in, and the organizational and industrial setting in which each innovation developed. These historical cases were supplemented with an extensive collection of baseline data (on resources, organizational arrangements, strategy, practice, and outcomes) to observe the present environmental and organizational settings of each innovation. The major part of the data collection process consists of observing the innovations as they develop over time. These longitudinal real-time observations include administering standardized questionnaires and interviews with all key people involved in each innovation every six months, as well as maintaining a qualitative research diary obtained from observing regular meetings of the management committees of each innovation.

At this time, none of the innovations are completed (i.e., have been implemented, entered the market, or been institutionalized). However, seven of the innovations have developed far enough to begin to identify patterns in their developmental process. This report focuses on the developmental processes of these seven innovations in the research program. A brief description of each innovation is provided below.

(1) The *hybrid wheat* study examines the research and development, marketing, and diffusion of a new strain of wheat seed for increasing the yield of wheat. This study concerns the entire industry and follows the innovative activity from the early 1950s up to the present. This innovation has involved both private and academic organizations.

Early emphasis on development of hybrid wheat was due to interest in increased yields and disease resistance. The latter was due an outbreak of stem rust blight which caused epidemic yield and quality losses in the 1950s. A variety of research occurred during the 1950s and commercial activity was stimulated by research discoveries in the early 1960s. During this same period the conventional wheat yields were also being improved in competition with the hybrid effort.

By the early 1970s major changes had occurred in the innovation participants. Almost all public institutions had dropped out as well as some of the private companies. This was primarily due to the high risk attributed to this research.

The first release of hybrid varieties came from two firms in 1978. This release proved premature due to difficulties with stability, impure seed stock, and low seed availability. This release was withdrawn and one of the firms subsequently sold its hybrid program.

Recent efforts in hybrid development have been more successful. Several firms

have released hybrid varieties and some 1983 tests have shown hybrid varieties to outperform varietal seeds.

(2) The *cochlear implant program* involves the development of an artificial, or bionic ear, which provides some profoundly deaf people an ability to discriminate sound. This program involves joint efforts by researchers and commercial developers. Alternative competing technologies are being explored. The development being tracked is a part of a larger firm with diverse interests,

Early development of this product began in the 1950s and 1960s but a concentrated effort did not begin until the early 1970s. Shortly after this new activity began, the chief researcher was censored by colleagues. They contended that it was improper to implant this technology when newer ones were expected to be developed soon. This controversy over choice of technology still remains with the current development.

Commercial effort by the company under study began in 1978 but did not gain momentum until the promotion of an early proponent. This individual asked that independent activities be pulled together into a coherent program under one manager.

Recent work has included two different technologies. One product was approved for sale by the FDA in late 1984. This product is now being actively marketed. Active research continues on the other technology.

The organizational context has also changed for this innovation. In late 1984 the reporting structure for this program was revised when it was placed with a group of other new product ventures. In late 1985 the program manager was changed and a new program manager was brought in from another project.

(3) *Therapeutic apheresis* is a new medical technology designed to remove specific pathogenic components of blood from a patient in order to treat specific diseases. This program is a joint venture between three firms. The innovation involves development of the separation technology as well as the choices of the diseases for treatment.

The initial conception of the product has been elaborated into five products involving two phases of technological development. During the most recent year the first product has been undergoing extensive field trials. These took place after the initial FDA approval was received in early 1985. The second phase of the technology was under development during most of 1985. Initial prototypes of the second phase were created at the end of 1985 for use in clinical trials.

In late 1985 budgetary reductions caused a change in the program planning. The development effort would not have funds for market entry as originally planned. This caused the development of a new program for the marketing of the device.

The organizational environment was also changing for two of the partners during recent times. In one case there was promotion of the vice president responsible for the innovation to a higher position. In the second case the division president resigned. This has led to other management changes including some changes in membership on the innovation management team. Despite these changes the program has been reviewed twice during 1985 and received good appraisals from the reviewers.

(4) The *naval systems program* is a multimillion dollar developmental effort by a defense contractor aimed at the development of a new weapons system for the

US Navy. This system includes a variety of process and management innovations and began in the early 1970s. Specific innovations have been identified in the area of factory automation, material management, strategic planning, human resources, and design-to-production transitions.

The Naval Systems innovation started with a major product failure amounting to several million dollars when the company could not deliver a quality product on time. As a result several changes in management occurred, including a change in general manager of the division, and an extensive program of quality improvement was initiated. This resulted in a proliferation of innovative ideas in human resources, materials management, factory automation, and strategic planning in order to ensure a quality product.

The Naval Systems innovation had direct involvement of the general manager over an extended period of several years. Almost no one in this organization, consisting of several thousand people, ever wondered what was on the general manager's mind as he personally directed many of the innovations which occurred. These innovations, which started with a stock, were eventually successful as a quality product was produced and follow-on program was initiated.

(5) The *site-based management of public schools program* is an administrative innovation which decentralizes the decision-making process in public school systems from the superintendent to school principals. This involves the shifting of responsibility from central administration to individual schools and the sharing of these responsibilities with representatives of the school's constituency.

This innovation started when the school district experienced budget cuts and a new superintendent was hired. The new superintendent brought along ideas of school-based management which could be used to operate the school district on a more decentralized basis. To implement the school-based management idea, committees were established in each of the individual schools in the district. This required a restructuring of the way in which each school was operated.

Throughout the entire implementation process the superintendent maintained a visible and direct role as leader of the innovation. Many ambiguities were encountered in implementing school-based management. These occurred because the concept was constantly being refined and defined. The concept was very new to the people involved and required a period of time for acceptance.

(6) The *strategic human resources management* program is an effort to transfer responsibility for traditional personnel-oriented activities of a human resources department to line managers of a large corporation. The goal is to replace the classic line/staff relationship with a new spirit of cooperation. Programs have begun to professionalize human resource management, develop line managers, integrate line and human resource management, and reconfigure the human resource organization.

The human resource innovation started with a new vice president of human resources. He was not satisfied with the apparent isolation of the human resources area from the line operations of the company. As a result he began discussing the idea that human resources would take on more of a line orientation while the line would become more human resource oriented. This evolved into several programs for implementation of these ideas which are still underway.

The vice president of human resources is personally leading this effort toward implementation throughout the company. Some restructuring will be required

as human resource people are assigned to positions or projects within divisions. Also extensive training of line management in human resource concepts is needed.

(7) The process of *creating a new organization* is being examined in the start-up of a computer software company. This company resulted from the merger of two new companies in 1983. These two companies had themselves been started in 1980. This innovation activity involves the development of new products in a rapidly evolving environment.

This case exemplifies a typical new start-up company with continual problems being encountered in financing the new products and in generating sufficient sales to remain viable. The software company started when one of the entrepreneurs decided to leave a secure job with a large company in order to start up the new venture. Many new products are being developed as the company continues to search for the right combination of new products which have market potential.

Two companies with similar interests were joined together in an effort to restructure things to take advantage of joint competencies. The new company is now exploring a joint venture with several other companies to gain needed capital and expertise. This case clearly demonstrates the fluid and rapidly changing pace of product innovation and the need to remain extremely flexible and responsive to the market in the initial stages of innovation. It also illustrates the problems in attracting capital and maintaining positive cash flow in the small firm.

PART II: OBSERVATIONS ON THE INNOVATION PROCESS

Case histories were developed for each of these seven innovations based on the core concepts and data collection procedures used in the Minnesota Innovation Research Program described in the previous section. These cases, along with the longitudinal updates and interviews with researchers, comprised the database for the development of key process observations discussed below. Initial observations of the innovation process were drawn from preliminary reports of one case and the research literature. Each author independently evaluated each of the seven cases to identify evidence of the process observations in each innovation. These independent evaluations were discussed until a mutual conclusion was reached about each process observation. The process observations were also generalized to apply to the variety of innovations examined here.

Six major observations were developed to summarize key characteristics of the innovation processes that were observed over time in the seven cases. These observations are of a descriptive nature. They are reflections of what did occur, not what should or should not have been done for success or failure. It is hoped that these descriptive observations can later be expanded into prescriptive actions as the longitudinal research progresses.

Table II summarizes the evidence observed across the seven case histories on the six observations, which will be discussed in detail below. Of the six observations, the most general evidence occurs for the propositions concerning shocks, setbacks, and restructuring. However, evidence for the remaining observations is also relatively strong, meaning that instances of the observations exist in all cases.

Table II. Evidence for Observations.

Proposition	Start-up Company Software & Hardware	Hybrid Wheat Industry	Cochlear Implant	Naval Systems	Therapeutic Apheresis	School-Based Management	Human Resources Management
1. Shocks	Entrepreneur Left a Steady Job to Start the Company.	Hybrids Needed to Solve the Wheat Rust Problem and to Improve Yields.	News of a "Bionic Ear" Being Developed in Australia	Major Product Failure. Multimillion Dollar Loss	Firm Approached with Opportunity for Joint Venture on New Technology.	State Budget Cuts Caused a Crisis. New Superintendent Hired.	New Head of H.R. Brought in from Outside.
2. Proliferation	Many New Products Developed After the Initial Startup.	Several Systems of Breeding Were Developed in the Different Companies.	Expansion into Hearing Health Business. Many Products	Major Innovations in Several Areas Were Started Including Human Resources Materials Management	Five Product Variations Were Created.	School Committees Were Formed. Each School Had Its Own Version.	Strategic Management Split into Four Action Programs
3. Setbacks & Surprises	The Need for Venture Capital Caused Continual Problems and Setbacks. Had Difficulty Marketing.	Firms Dropped Out of the Program after Spending Great Amounts of Money.	Bad Quality. Management Changes.	Material Management Suffered Several Reversals from the Original Idea	Cutbacks in the Budget Caused Program Revisions. Changes in Target Diseases.	Several Attempts Needed to Develop Staff Leader Role.	Difficult to Get All Departments Involved.
4. Degee of Linking Old & New	No Old Yet	New Hybrid Wheat Comes from the Old. New Yield Must Exceed the Old.	Old–Single New–Multichannel	The Line is Learning to Work as Teams. Old and New Products in the Same Organization	Three Phases of Product Being Developed: Current, New, and Future.	Teachers Learning to Administrate, Administrators Learning to Delegate	The Line Learning Staff Roles, the Staff Learning Line Roles.
5. Restructuring	Two Companies Were Joined to Form the New One. Developed License Arrangement.	Created Separate Laboratories for Hybrid Wheat. Mergers Occurred	Joint Venture Used. Also New Program Formed	Transition Teams Formed. Organizational Charts Constantly Changing	Joint Venture Formed. Spin-off from Corporate Division.	The Innovation Itself is a Restructuring of Teams which Cross Traditional Lines	Partial Decentralization of the H.R. Function.
6. Hands-on Top Management	Two Entrepreneurs Were the Driving Force in All Innovations.	V.P. Research Involved at One Company.	Div. V.P. Involved on a Frequent Basis	Pervasive Influence of the General Manager. A Blitz of Memos	Constant Attention by the Div. V.P. Some Attention by the CEO.	The Superintendent Pushed the Idea Constantly.	Head of H.R. is Leading the Effort Personally.

Observation 1

Innovation is stimulated by shocks, either internal or external to the organization.

An overall observation from the seven case studies is that innovation was more prevalent when some major change occurred in the organization or its environment. Ideas were often generated but are not acted upon in an organization until some form of shock occurred. Shocks included such things as new leadership, product failure, a budget crisis, and an impending loss of market share, although it is evident from the participants in our project that a shock can come in many different forms.

In the naval systems program, a major failure in a product improvement program caused the organization to expend considerable effort to uncover the underlying problems in the organization. The shock resulted in more attention to manufacturing by management as well as an increased emphasis on Human Resource Management.

In two of the cases, a new leader in the organization was the shock required to initiate innovation. In the strategic human resources management program, the personal vision of a new leader was needed to get line managers to think as Human Resource managers and vice versa. In a local school district, new leadership combined with a major budget crisis caused a total rethinking about managing schools in a more decentralized manner.

In the hybrid wheat industry, the impetus for developing the hybrid was a disease called stem rust blight. A hybrid variety of wheat was expected to resist this disease and provide better yields.

Shocks do not need to be viewed as negative. In Therapeutic Apheresis the approach by another company with an offer to enter into a joint venture opportunity was seen as the shock necessary for the renewal of an abandoned effort.

Thus, in all seven cases, efforts to begin work on an innovation can be traced to some kind of shock which stimulated peoples' action thresholds to pay attention and initiate novel action. This process observation is consistent with the general belief that necessity, opportunity, or dissatisfaction are the major preconditions for stimulating people to act. March and Simon[8] set forth the most widely accepted model by arguing that dissatisfaction with existing conditions stimulates people to search for improved conditions, and they will cease searching when a satisfactory result is found. A satisfactory result is a function of a person's aspiration level, which Lewin et al.[28] indicated is a product of all past successes and failures that people have experienced.

This model assumes that when people reach a threshold of dissatisfaction with existing conditions, they will initiate action to resolve their dissatisfaction. However, while a given event may be perceived as a shock and stimulate action for some people, it may not do so for others. This is because individuals have widely varying and manipulable adaptation levels.[29,30] When exposed over time to a set of stimuli that change very gradually, people do not perceive the gradual changes—they unconsciously adapt to the changing conditions. Their threshold to tolerate pain, discomfort, or dissatisfaction may not have been reached. As a consequence, opportunities for innovative ideas are not recognized. In general, we would expect that personal confrontations with the sources of problems or opportunities are needed to trigger the threshold of concern and appreciation required to motivate most people to act.[31] Shocks serve this function in stimulating innovation.

Observation 2

An initial idea tends to proliferate into several ideas during the innovation process.

An initial idea tends to proliferate into several ideas during the innovation process. More generally, proliferation of ideas, people, and transactions over time is a pervasive but little understood characteristic of the innovation process, and with it comes complexity and interdependence—and the basic problem of managing part–whole relationships.[7]

As we observe the innovations develop over time, in all cases it was found that the initial ideas that served to stimulate the innovation projects proliferated over time into an increasing number of alternative paths, and it is often impossible to know which paths may yield fruit. Some ideas go on the "shelf" for a long time. Others lead to important innovation spin-offs. Still others converge at later times as central to making the innovations a reality. For example, in the case of hybrid wheat's development, three alternative paths were followed simultaneously, and it took several years of extensive investments in each path to determine which path was appropriate in developing a hybrid strain of wheat.

Moreover, most innovations being studied do not consist of a single new device, product, or procedure. Instead, families of related new products and procedures are being developed to create sufficient critical mass and penetration to become commercially or organizationally viable. This exponentially increases the complexity of managing innovation. For example, in the development of therapeutic apheresis, the initial product idea has already proliferated into five product ideas. The cochlear implant innovation has expanded from initial work on a single channel device to current developments of six new devices using three different technologies. While these new ideas and products are at different stages of development, work on them tends to occur simultaneously by different and overlapping subgroups within the innovation programs.

As a consequence, the cases show that managing an innovation over time usually involves linking overlapping cycles of development efforts. Each cycle may require linking R & D, prototype development, testing, manufacturing scale-up, and marketing activities for a given product. However, subsequent cycles must be simultaneously integrated in order to create a related family of products, and yet differentiated enough to permit creation of a unique new product or component.

As these preliminary observations suggest, after an initial shock which stimulates a simple unitary progression of activity to develop an innovative idea, the innovation process soon proliferates into a multiple divergent progression of developmental activities, as Van den Daele[25] described. Some of the activities in this diverging multiple progression are conjunctive (or related by a division of labor among functions to develop a given alternative), while many activities are unrelated as disjunctive alternative paths pursued by different people or organizational units. As a consequence, after a short initial period of simple progression of a unitary set of activities, the management of innovation soon proliferates into an effort of trying to direct controlled chaos.[12] As one manager stated, "The problem is like trying to grow an oak tree when there are inexorable pressures to grow a bramble bush."

Observation 3

In managing an innovation effort, unpredictable setbacks and surprises are inevitable. Learning occurs whenever the innovation continues to develop.

There is no doubt that setbacks or surprises result in any innovation process. Organizational learning can result from these setbacks as the innovation progresses. Understanding the learning process has, in fact, been prescribed as a better method of management than attempting to remove all setbacks and surprises.[32]

The foremost example of setbacks and the positive learning which can result is found in the naval systems case. In this case, a major product failure occurred, resulting in a major loss. However, from this failure, the company created a learning process and vowed never to have this happen again. The actual experience was documented in a case history which is used in divisional training. The product failure also resulted in a major thrust in the human resources management area.

In several of the other cases, multiple setbacks have also occurred to date. In hybrid wheat, the first commercial release of the seed failed due to contamination. Genetic problems also were uncovered in the primary breeding source. In school-based management, the high school staff rejected the new process, requiring many amendments. The therapeutic apheresis project faced reduced funding levels, as well as an initial field failure of a unit due to a poor user interface. Finally, the cochlear implant innovation has had to deal with the recall of a newly introduced product in the market, a change in program management, along with failures to complete negotiations on joint agreements with competitors.

In general, learning tends to occur in three ways: (1) by imitation of something done elsewhere, (2) by extrapolation from the past into the future, and (3) by trial-and-error through error detection and correction.[32] New-to-the-world innovations must rely primarily on trial-and-error learning, along with a little extrapolation. Imitation is not possible for there is no precedent to follow or copy. The necessary (but not sufficient) conditions for trial-and-error learning are that setbacks and errors are detected and corrected.

Error detection requires: (a) knowledge of desired or expected outcomes, (b) an ability to discriminate substantive issues from "noise" in the system, and (c) a felt freedom to communicate knowledge of errors or setbacks to appropriate individuals. As Van de Ven[31] found in his study of planning new organizational start-ups, error detection was pervasive in the innovation cases. Indeed, in repeated interviews with innovation participants and observations of their meetings, the researchers obtained extensive lists of reported mistakes or "red flags" by participants in the development, schedule, or direction of their innovations over time.

However, while there are differences among the innovation cases, in general, relatively few attempts were observed to correct these reported mistakes. Different reasons appear to exist among the innovation cases for this observed lack of error correction when extensive errors are detected: (a) lack of recognition of who is responsible for an error, (b) lack of slack resources and tight project deadlines limit the time available to address mistakes, (c) the use of group problem-solving processes that avoid or smooth over conflicts, and allow errors to fester and grow

into larger mistakes, and (d) loss of memory for retaining past learning experiences through personnel turnover and inadequate documentation of developmental processes.

The fact that many detected errors were not corrected appears to have two consequences on the innovation process. First, as Van de Ven[31] observed, when errors are not corrected, they "snowball" over time into vicious circles of even larger and more intractable complexes of problems resulting, as in the cochlear implant case in the replacement of the program manager. Alternatively, as Masuch[33] suggests, the vicious circle may lead to organizational stagnation, apathy, or failure. A second consequence is that errors and mistakes are the major sources of learning by trial-and-error. Each failure to correct a detected error represents a lost opportunity for learning in the development of an innovation.

Observation 4

As an innovation develops, the old and the new exist concurrently, and over time they are linked together.

Whenever an innovation develops within an existing organization, the old and the new must exist concurrently, as parallel streams of activities. The new innovation often represents a threat to the old established order and thus, there is opportunity for establishing new organizations and linkages. These relationships between old and new may also exist between organizations and between products.

Where new products have proliferated, as in therapeutic apheresis and cochlear implants, convergent relationships exist between current versions and future product versions. This is particularly salient where multiple products are under development simultaneously. In some situations product changes gave way to organizational changes as well.

In the naval systems innovation, a major linkage was observed which involved the redesign of the production facility to product two different products simultaneously. Although the products are somewhat similar, the production processes required for the new product are quite different. This effort is still underway and a special group was formed to develop this integrated facility. In this situation, the old and the new are co-existing simultaneously for several years under the same roof.

In the human resources and school-based management cases, new administrative processes were introduced which differed greatly from the existing processes. In both cases, there was evidence of tension between the old and new and in the human resources case, implementation has not yet occurred, possibly because sufficient linkages between old and new have not been created. The school-based management innovation has required many linkages to approach implementation. These have been formed through the use of several meetings with the involved parties (the teachers, the union, and administrators) as well as cross-functional committees which address issues.

The implication of this observation is that innovations are often not simple additions to or replacements of existing organizational programs. Instead, if they are to be implemented and become institutionalized, the new innovations must overlap with and become integrated into existing organizational arrangements. In other words, after a period of divergent and parallel streams of activities, we begin to observe convergent paths of activities that link the innovations with ongoing

organizational operations. The management of convergent integration processes appears to take several forms, as described in our next observation.

Observation 5

Restructuring of the organization often occurs during the innovation process. This restructuring can take many forms including joint ventures, changes in organizational responsibilities, use of teams, and altered control systems.

We have already noted that the innovation process entails a period of divergent proliferation of activities, parallel streams of alternative innovation paths, and then convergent integration of the coexisting old and new programs. One of the ways that the managers in the case studies handled these divergent, parallel, and convergent streams of progression was by changes in the organizational structure. Organizational changes observed included formal and informal as well as temporary and permanent changes.

In the naval systems innovation, both formal and informal organizational restructuring has been observed. A materials management department was created by redefining responsibilities and needs. Prior to this reorganization, these functions were performed in many different segments of the organization. Another formal structure used in this company was the assignment of a design-to-production manager with a group concerned with the producibility of the product early in the design phase. As the product design became more established, this group was moved from engineering into production departments. Most of the group was absorbed into the production area, with only one or two key individuals maintaining a matrix relationship with engineering. Finally, this company also uses groups referred to as transition teams, cross-functional and ad hoc in nature, whose charge is to solve specific problems in the transition of the product into production.

In the therapeutic apheresis innovation, a Strategic Business Unit (SBU) was established linking the major companies in the joint agreement. In addition several problem-oriented groups have also been formed as needed. For example, a so-called "phoney group" was established among different functional specialists between the organizations, who conducted telephone conference calls as needed when problems arose. In the human resources management innovation, an ad hoc task force was created to define "what was fixed and what was variable" about human resources in the company. Finally, the school-based management innovation required the creation of a district curriculum council and an overall leadership committee.

In each of these cases, many interdisciplinary functions needed to be combined to address issues regarding the innovation. Although the importance of integration and coordination mechanisms have long been recognized in the innovation literature (e.g., Galbraith[34]), we were surprised to observe the number, fluidity, and variety of creative mechanisms used in the innovation cases to restructure, coordinate and address problems. These mechanisms provided incremental ways to make continual transitions between divergent components of the innovations and between the new innovations and existing organizational operations throughout the innovation period.

Observation 6

Hands-on top management involvement occurs throughout the innovation period. Several levels of management removed from the innovation itself are directly involved in all major decisions.

The literature has frequently mentioned sponsorship and product champions.[35–37] However, we observed in the innovation cases much more than a management sponsor or product champion, which the literature has focused upon. Top managers, meaning one to four levels removed from the innovation, were observed in many of the cases to be: (1) very knowledgeable of and keenly interested in the innovations within their organizations, (2) directly involved and to apply different criteria among each other in all major decisions about the innovations, and (3) perform different technical, managerial, and institutional roles which were critical to the innovation developmental effort but often not recognized by the immediate innovation unit managers. Having multiple levels of managers involved in the innovations appeared to provide balance among ever-present contradictory forces for expansions and contractions in program scope, resource allocation, time schedule, and performance targets. These levels of management also "ran interference" for the innovation, helped in controlling proliferation, assisted in restructuring, and helped get the necessary resources.

Thus, we observe a set of very active "hands-on" roles not only for one upper-level manager, but by hierarchical teams of top managers. While these managerial roles appear to vary as different problems or opportunities unfold for an innovation, managerial involvement does not appear to diminish over the life-cycle of innovation development. The degrees of time involvement of top managers appear to remain relatively constant over time in the longitudinal tracking of the innovation studies thus far.

In the cochlear and therapeutic apheresis projects, top management frequently monitors the progress of the innovations and became directly involved in operational decisions when significant problems arose, such as a product recall, replacement of a program manager, and in conflicts over the technological directions of the innovations. These activities involved the CEO, sector and group vice-presidents, and division general managers in which the innovations were housed. They were observed to take high levels of personal interest and ownership in the projects and provided the necessary clout to get things done.

The other innovation cases also exemplify the active "hands-on" roles of top managers. In the school-based management innovation, the superintendent pushed the idea throughout the district even though committees were set up in each school to decide on the details. In the case of naval systems the general manager of the division, two levels removed from most of the innovations, provided constant direction and support. He ran interference, provided the budget and was a key participant in all major decisions.

PART III: AN EMERGING INNOVATION PROCESS MODEL

We have described above six process observations about how a variety of technical and administrative innovations evolve over time. These observations are grounded in data about seven innovations that are being intensively studied over time. The

observations now need to be unified into a coherent process model about innovation.

Figure 2 is helpful in describing how all of these observations fit together. Imagine that the organization is proceeding in the general direction of point A as shown in Figure 2. At time zero a shock occurs which propels an idea or innovation in a new direction B. As indicated earlier, this shock may be a budget crisis, product failure, change of management, or environmental change which brings the new idea into being and provides a discontinuity in the old organization. So, the innovation is now moving in direction B while the organization is still moving toward point A.

As the innovation begins to be implemented in the organization we see that proliferation of the new idea occurs, and a divergent multiple progression process begins to emerge. This is represented in Figure 2 as a branching out of the original idea into several ideas. This proliferation may represent several new product variations spinning out of one original new product idea, or several related ideas which are required to get the original innovation implemented. As long as these proliferating ideas are, at least, loosely related the innovation still proceeds toward point B, although it now has multiple divergent and parallel paths of progression.

As work proceeds on the ideas over time, setbacks and surprises are encountered. This is shown in Figure 2 by the lines which represent setbacks and terminations. While some setbacks are treated as aborted dead ends to certain paths in the innovation process, more often they are terminated as incomplete or not-immediately useful ideas or components for progressing with the innovation at that point in time. These terminated ideas or components are often stored away in memory or placed on the "shelf" for possible subsequent use. For an ongoing organization that undertakes multiple innovations over time, these terminated ideas or components become a rich store-house of knowledge and materials for use in unforseen ways in subsequent innovations. Indeed, in one of the organizations which houses one of the innovation cases, an internal study found that

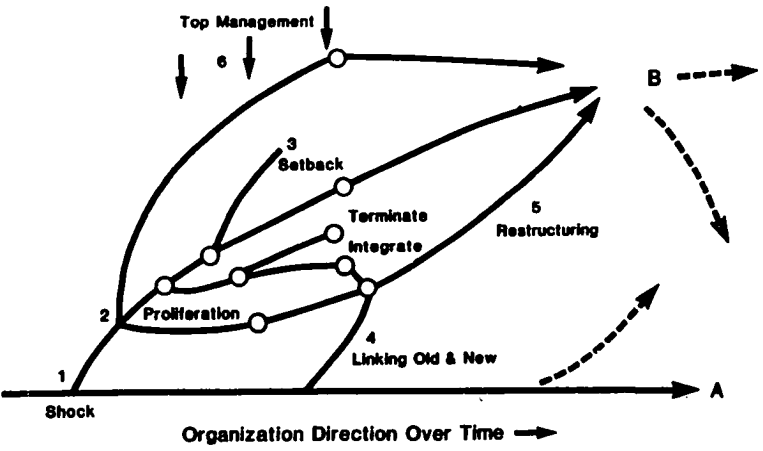

Figure 2. Illustration of Emerging Innovation Process Model.

the average "shelf-life" of incomplete innovative ideas or materials was nearly ten years, and most often those embryonic ideas or compounds were incorporated in totally unforseen and unpredictable ways in subsequent commercially successful innovations. As Alexander Gray stated, "No point of view, once expressed, ever seems wholly to die . . . our ears are full of the whisperings of dead men."

As the innovation develops further, convergent linkages are established by integrating different component paths of the innovation, as well as by overlapping the old and the new. These linkages are represented in Figure 2 by lines which connect different paths of the innovation and by the converging lines between the operating organization moving toward point A and the innovation moving toward point B. This process of multiple convergent progression appears to take three forms: (1) the old organization can be moved toward point B, as the entire organization fundamentally changes direction as a result of the innovation, or (2) the innovation can be moved toward point A and blended into the old organization, or (3) the old and new can coexist in parallel progression with linkages between the old and the new. All of these kinds of linkages appear to occur throughout the life cycle of the innovation cases in this study.

Also, the organization is constantly being restructured as it moves toward point B. This is shown in Figure 2 by the entire course of events. The initial shock may require restructuring, proliferation requires restructuring, setbacks and surprises may require restructuring, and linkages require restructuring. This restructuring may take the form of changes in organizational responsibilities, joint ventures, teams, new departments being formed, or altered control systems.

Finally, hands-on top management takes place all along the route toward point B as shown by a continuous input by top management in Figure 2. Top management controls proliferations, deals with setbacks, helps to link the old and the new, and restructures the organization as needed, in addition to providing general goals and resources to support the innovation.

What we have been describing, through our process observations and Figure 2, is quite different from theories which have been proposed in the literature. First, our process model is grounded in data and is empirical in nature. As such it is descriptive of how innovation evolves over time. No attempt is made here to describe a normative theory of innovation. This would seem to require another step which is relating descriptions of innovation processes to success and failure. But our descriptive observations are a good step toward developing and testing normative theories.

The process model we have described here does not resemble the unitary sequential stage theories found in the literature. As a matter of fact, we have observed innovation to unfold from a simple unitary process into multiple divergent, parallel, and convergent progressions of activities over time. Some of these activities in the multiple progression process are conjunctive (i.e., related through a division of labor among functions and interdependent alternative paths of activities), and many appear to be disjunctive (i.e., unrelated in any noticeable form of functional interdependence). Moreover, we observed that many components and paths that innovation participants perceived as being interdependent and conjunctive at one time, were often reframed or rationalized as being independent and disjunctive at another time. In either case, it is clear that the messy and complex progression observed in the innovation cases cannot be reduced to a

simple sequential progression model of stages or phases as the vast majority of process models in the literature suggest.

Finally, the process model we have proposed here relates specifically to innovation. Most other process models found in the literature represent less discriminating and more general process models of individual and organizational decision making, development, and change.

CONCLUSIONS

In this article we have proposed a descriptive process model of how innovation evolves over time. This model is based on an in-depth review of the longitudinal development of seven innovations. These innovations include four new product technologies and three new administrative arrangements.

Using the seven innovations, we have developed six observations about how innovation evolves over time. These six observations describe a rather fluid process where innovation seems to start off with a shock, then proliferates, is subject to setbacks and surprises, and then links with the old organization along the way. Restructuring of the organization occurs and top-management maintains hands-on involvement until the innovation finally becomes part of the accepted order or establishes a new order.

This process stands in contrast to the many sequential stage models which have been proposed in the literature. We conclude that a much more complicated multiple progression process of divergence, parallel, and convergent streams of activities occur in the development of innovations. Moreover, while some of these streams of activities are interdependent and conjunctive, many appear to be disjunctive and occurring independently of other streams of activities.

Of course, it should be recognized that these observations and the resulting process model that emerged inductively are preliminary. In the future this process model will be more extensively developed and modified, if necessary, as data collection and updates on these innovations continue over time in the Minnesota Innovation Research Program. Longitudinal tracking of these innovations is providing a rich database which will be suitable for more detailed understanding of the process of organizational and technological innovation.

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