SYSTEMS DESIGN AND THE PROMOTION OF POLLUTION PREVENTION: BUILDING MORE EFFECTIVE TECHNICAL ASSISTANCE PROGRAMS

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I. INTRODUCTION

As a concept, pollution prevention (P^2) holds considerable promise. In many corporations, P^2 programs reduce material, pollution abatement, and regulatory compliance costs. These programs increase the efficiency of material and energy use, reduce demands on natural resources, and minimize the production of waste. As such, pollution prevention appeals to both environmentalists and corporate leaders.

As a policy tool, however, P^2 is difficult to implement. Traditional policy tools lack flexibility. The two dominant environmental management systems—environmental regulations and market-based incentives—are rule-based systems that standardize treatment of firms. Neither allows policy makers to strategically promote pollution prevention. Yet flexibility and strategic choice are essential aspects of pollution prevention. P^2 works best when highly contextualized; to succeed, sustainable technologies and production processes must be adapted to the specifics of a particular facility. Furthermore, operating procedures must evolve to maximize the benefits of these adaptations. Such changes are difficult to orchestrate from the outside.

A tension exists. Pollution prevention is essentially managerial, and the strategies require detailed *intra-organizational* knowledge

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of the firm to succeed. At the same time, managers will adopt such strategies only if they possess sufficient *knowledge* to understand the potential of P^2, *incentives* to utilize that knowledge, and *organizational capacity* to design and implement solutions. Many firms lack such knowledge, incentives, and organizational capacity.

One role of public policy, then, is to provide the *extra-organizational* supports needed for firms to engage productively in pollution prevention. Many states view knowledge-based, context-sensitive consultations as essential for effective diffusion of innovative P^2 technology and managerial practices. Consequently, 49 states have instituted over 105 technical assistance programs aimed specifically at environmental compliance and pollution prevention.

The need for extra-organizational assistance to support intra-organizational capacity is particularly important for mid-sized firms. Small firms have relatively flat decision making structures, with few departmental differentiations; mid-sized firms (those with more than one facility, each of which employs more than 100 persons) are organizationally more complex. Nevertheless, many mid-sized firms lack the technological and organizational capacity to design and implement pollution prevention programs. Support from technical assistance programs (TAPs) can be particularly useful to these firms.

While they supply the extra-organizational supports needed for pollution prevention programs, many TAPs still have narrowly defined objectives. Strategies to transfer pollution prevention practices all too often focus on technological solutions, with little emphasis on the managerial and organizational capacity of the firm. Such strategies are problematic, particularly when applied to mid-sized firms.

This Article contends that pollution prevention TAPs must increasingly build managerial capacity if they wish to effectively promote pollution prevention. Without such assistance, pollution prevention programs will fail to achieve their full potential.

We demonstrate this in Part II, where we examine the impact of a TAP on a hypothetical company. Traditional TAPs are inadequate to foster organizational changes that enhance a firm's capability to prevent pollution. The shift from environmental management to pollution prevention focuses the analysis on the entire manufacturing system rather than on the "end of the pipe."

Part II suggests that pollution prevention TAPs themselves need to change their services; TAPs must move from solving particular problems to providing tools that help companies solve their own problems.

Part III uses systems thinking to illustrate the organizational complexity of pollution prevention approaches compared to the waste management practices of the past. Companies organize themselves in units reflecting the typical production process. Unfortunately, these organizational units become competitive components whose independent goals destroy the systemic functioning of the firm. Part III discusses the impact of systems, corporate culture, and management style on a firm's environmental performance.

Finally, Part IV analyzes the pollution prevention activities in mid-sized firms. These firms are organizationally more complex than smaller firms, yet are more dependent on outside financial and technological resources than larger firms. Their significant environmental impacts make them an ideal sector for pollution prevention TAPs. Part IV suggests that pollution prevention TAPs need components that address the systemic nature of both the technological problem and the decision making structure in these firms.

II. THE NEED TO TRANSFORM TAPS

A. A HYPOTHETICAL COMPANY

The environmental manager at Complete Coatings, Inc.[1] is concerned about the rising cost of hazardous waste disposal and is under pressure by the plant management to keep such costs to a minimum. The company's manufacturing processes include a coating step that generates hazardous waste from equipment cleaning and overspray in the paint booth. The environmental

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[1] The experience of Complete Coatings, Inc. is a composite of experiences with firms receiving assistance from the author's university-based technical assistance program.

manager contacts the university-based TAP for help.[2] She attends a technical training program conducted by the TAP and works with the TAP to analyze waste production within the plant. The TAP recommends a strategy to reduce the company's regulatory burden using the following pollution prevention techniques: (1) less hazardous coatings, (2) more efficient application equipment, (3) scheduling changes that reduce cleaning steps, and (4) a production process change that eliminates the use of benzene from the plant. Six months later the TAP contacts the company and learns that the company changed the production schedule and instituted better operating procedures. The environmental manager explains that changes in the product and production equipment were beyond her power. The TAP chalks up a relatively successful technical assist.

A year later Complete Coatings conducts its first Toxic Release Inventory.[3] The firm discovers that its coating process emits a surprising amount of volatile organic compounds (VOCs) and that it may need an air permit. The company also finds itself on a local newspaper's list of the fifty top toxic polluters in the region.

The environmental manager receives an agitated call from the plant manager and contacts the TAP for help. She attends a second training workshop, and at her request, the TAP conducts further analysis of the plant. The TAP submits a new report to the

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[2] Voluntary technical assistance and technology transfer between a government sponsored program and industry usually proceeds as follows: The technical assistance program (TAP) targets small-to-mid-sized companies through direct advertising or local chambers of commerce and other industry organizations. A company realizes it has some urgent problem, either with regulatory compliance or escalating costs of waste disposal. The company calls the TAP and sets up an appointment for an on-site assist or describes the problem over the telephone and receives information by mail. The TAP sends out a trained professional to collect information about the company's production and waste management processes by reviewing documents and interviewing managers and shop floor employees. Often, the shop floor employees provide valuable insight into the problem and potential solutions. The TAP professional returns to the office and writes a technical report that characterizes the problem and recommends possible remedies. The report is sent to the company manager for review and implementation. The TAP contacts the company six months later to discuss progress and evaluate the implementation rate of the recommendations.

[3] Under the Toxic Release Inventory (TRI), a company submits an annual report on whether it has released any of over 300 toxic chemicals to the air, water, or land, or in off-site transfers. Companies with 10 or more full-time employees in Standard Industrial Classification Codes 20-39 and that manufacture, process, or otherwise use the listed chemicals in excess of specified thresholds must complete the TRI forms for each chemical and submit them to the EPA by July 1.

plant manager. The report once again recommends that the company install more efficient application equipment, substitute a less hazardous coating for the current one, and adjust the production process to compensate for this material substitution. If implemented, these changes would sufficiently reduce Complete Coatings' VOC emissions to eliminate the need for an air permit.

Six months later the TAP contacts the company and learns that the original environmental manager has left the company, that it now uses better application equipment, and that the company obtained from the state an air permit that allows for a planned plant expansion. Although the company is pleased that it is no longer on the list of top polluters, the production manager is not implementing the material substitution and process recommendations. "Our current system works fine," he notes.

The TAP staffers take pride in companies such as Complete Coatings. Compared to working with companies that ignore advice, working with Complete Coatings produces real satisfaction. Yet, the TAP managers remain uneasy. TAP staffers refer to the Complete Coatings of the world as technical assistance "junkies." These are companies that rely on the TAP for assistance with every "new" problem. The reappearance of familiar faces at the TAP causes the staffers to wonder about the role of the TAP in these companies' decision making processes and question the effectiveness of the types of assistance they provide.

Although the TAP gave away "a lot of fish," the staffers feel they have not taught many companies "how to fish." All too often, environmental managers remain isolated, implementing changes in their sphere but having little impact on systems of production, operations, and maintenance. To design more effective technology transfer policies and programs, the TAP needs to better understand the impact of a firm's organizational culture on the types of decisions required for pollution prevention.

B. TECHNOLOGY TRANSFER AND POLLUTION PREVENTION

Dearing broadly defines technology transfer[4] as "the communication of information which is put to use."[5] The *technology* can be anything from information that influences decision making to knowledge about how a particular technology works.[6] Examples of technologies applicable to pollution prevention include planning processes and performance characteristics for high-volume, low-pressure coating application equipment. The planning process will guide decision making, while the performance characteristics will explain function.

The challenge for TAPs is the *process* by which the information is transmitted and received. Although *transfer* implies a unilateral movement of information from those conceiving it to those using it, more often the relationship between the participants is multilateral or bidirectional. Dearing concludes that "technology transfer is a complicated relational concept, which involves communication, information, use and time."[7] Most TAP professionals "tap" into the knowledge of the shop floor employees and the lower level managers for insight into possible solutions. The character of the technology transfer relationship becomes more bidirectional or participatory as the focus of activities moves into the innovation phase of product development.[8]

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[4] The terms technical assistance program (TAP) and technology transfer program are used interchangeably.

[5] J.W. Dearing, *Rethinking Technology Transfer*, 8 INT'L J. TECH. MGMT. 478, 479 (1993).

[6] The literature is packed with various definitions of technology transfer; however, most of the more complicated definitions boil down to the simple definition given by Dearing. *See supra* note 5 and accompanying text (discussing Dearing's definition); *see also* Thomas P. Evans, *Triggering Technology Transfer*, 65 MGMT. REV. 26 (1976) (defining technology transfer as the movement of technical ideas and knowledge from conceiving organization to user organization); Erich Staudt et al., *Technology Centres and Science Parks: Agents or Competence Centres for Small Businesses?*, 9 INT'L J. TECH. MGMT. 196, 197 (1994) (stating that technology transfer "designates a process whereby the specific know how of a particular region and its reservoir of education and research institutions is transferred to companies in a maximally efficient way").

[7] Dearing, *supra* note 5, at 479.

[8] *See* Elizabeth Starbuck, *Biological Model for Technology Transfer in University-Industry-Government Partnerships*, 1994 TECHNOLOGY TRANSFER PARTNERSHIP PROCEEDINGS 87 (proposing a biological model for the technology transfer process between the university and industry). Starbuck defines the transfer process as a cell, in this case the Engineering Research Center funded by the National Science Foundation, bounded by membranes that

Traditionally, TAPs improve the effectiveness of the technology transfer process by reducing the actual or perceived differences between the programs and their clients.[9] One byproduct of this strategy is the development of specialized TAPs designed to resemble the organization of the companies they serve. Often a state will have separate TAPs for environmental regulatory issues, pollution prevention, worker health and safety, productivity and quality enhancement, management and general business assistance, and energy conservation. These TAPs conceptualize the problems at a manufacturing site in the same manner as their industrial counterparts.

The goal of a pollution prevention TAP is to reduce pollutants at the source[10] or, at the very least, to move a company up the waste management hierarchy from disposal to source reduction.[11] The

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emit and receive information. *Id.* The cell membrane receptors, which represent people, are classified into any or all of three functions: gatekeepers, boundary modifiers, and transmitters. Gatekeepers are individuals to whom others often turn for information, while boundary modifiers are people who can change policies and procedures. Finally, transmitters are those who indirectly promote technical ideas and perpetrate change. *Id.*

[9] Dearing, *supra* note 5, at 482. Dearing discusses the relationship between research on communication networks and innovation. He uses the concepts of homophily (the degree to which people are alike) and heterophily (the degree to which people are different) and their relevance to communication networks to conclude that "the ultimate relationship for technology transfer to occur readily would be one in which participants are quite homophilous on all criteria [perceptual, relational, situational, organizational, social, and/or cultural] except for the technical expertise in question." *Id.* (citing Everett M. Rogers & Dilip K. Bhowmik, *Homophily-Heterophily: Relational Concepts for Communication Research*, 34 PUB. OPINION Q. 523 (1970)).

[10] The Pollution Prevention Act of 1990 defines source reduction as

> any practice which (i) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and (ii) reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants. The term includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvement in housekeeping, maintenance, training, or inventory control.

42 U.S.C. § 13102(5)(A) (Supp. V 1993).

[11] The Pollution Prevention Act of 1990 reinforced the waste management hierarchy established in the Hazardous and Solid Waste Amendments of 1984 (HSWA), Pub. L. No. 98-616, 98 Stat. 3221 (codified as amended in scattered sections of 42 U.S.C.), to the Resource Conservation and Recovery Act of 1976 (RCRA), Pub. L. No. 94-580, 90 Stat. 2795 (codified as amended in scattered sections of 42 U.S.C.), and expanded it to include discharges of pollutants in all environmental media. The 1990 Act states:

complexity of the task for the TAP and the company increases as the focus of activities moves from disposal to source reduction. As a company moves up the waste management hierarchy, the options require more integrated evaluation and decision making across functions in the plant. The organizational factors associated with more advanced options also include the company's capacity to be innovative in the face of uncertain technologies and outcomes.[12] For example, the decision at Complete Coatings, Inc. to ship its paint-related wastes off site for disposal could be made by the environmental manager alone, whereas the decision to substitute a less hazardous coating requires consideration by the top management, customers, product designers and engineers, process technologists, the safety manager, and the environmental manager.

Pollution prevention TAPs[13] strain against the boundaries of

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> The Congress hereby declares it to be the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

42 U.S.C. § 13101(b) (Supp. V 1993).

[12] Alan Pearson identifies key characteristics for innovation:

> the importance of observant people, the value of experience, the linking of different technologies to turn failure into success, the need for perseverance, the contribution of group problem solving techniques, the potential for opening up a wide range of opportunities and for changing, even destroying, existing organizational and market structures.

Alan W. Pearson, *Managing Innovation: An Uncertainty Reduction Process*, *in* MANAGING INNOVATION 18, 20 (June Henry & David Walker eds., 1991). Pearson presents a matrix charting uncertainty about the output versus uncertainty about the process. Both axes range from low to high, and he defines the four quadrants as: (1) exploratory research (high, high); (2) development engineering (low, high); (3) applications engineering (high, low); and (4) technical-market combination (low, low). *Id.* at 22.

[13] A recent U.S. General Accounting Office report identified 105 state pollution prevention programs and classified 20% of them as regulatory and 80% as nonregulatory. U.S. GEN. ACCOUNTING OFFICE, GAO/PEMD-94-8, REPORT TO THE CHAIRMAN, SUBCOMM. ON ENVIRONMENT, ENERGY, AND NATURAL RESOURCES, H.R. COMM. ON GOVERNMENT OPERATIONS, POLLUTION PREVENTION: EPA SHOULD REEXAMINE THE OBJECTIVES AND SUSTAINABILITY OF STATE PROGRAMS 3 (1994) [hereinafter GAO REPORT]. Regulatory programs incorporate pollution prevention concepts into the existing regulatory framework or implement new pollution prevention planning requirements. *Id.* Nonregulatory programs focus on voluntary technical assistance, education, and outreach. *Id.* at 4.

traditional technology transfer programs and the limited conceptual frameworks they and their industrial counterparts use to define issues at the manufacturing plant. The goal to change a company's view from *environmental management* to *pollution prevention* represents a shift away from an atomistic view of the plant, which requires problem-oriented technical assistance, to a systemic view of the plant, which uses goal-oriented technical assistance.[14] The strain is *caused* by the perception of pollution prevention as just an environmental issue and not as part of a larger system that includes product design, manufacture, distribution, and use. The challenge is to design a technology transfer program that promotes enduring, widespread, organizational changes that prevent pollution through systemic evaluation and decision making.[15] The

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[14] For more on the shift from problem-orientation to goal-orientation, see generally EDWARD DE BONO, SERIOUS CREATIVITY: USING THE POWER OF LATERAL THINKING TO CREATE NEW IDEAS 71, 192-93 (1992) (distinguishing between "achievement thinking" (Japanese focus on continuous improvement) and "problem avoidance" (western focus on faults)); ROBERT L. KUHN, MID-SIZED FIRMS: SUCCESS STRATEGIES AND METHODOLOGY (1982) (emphasizing need for strategic planning (action guided by defined goals and objectives) rather than incremental planning (reaction to unexpected shocks to system)); PETER M. SENGE, THE FIFTH DISCIPLINE: THE ART AND PRACTICE OF THE LEARNING ORGANIZATION (1990) (explaining fundamental ideas of systems thinking, personal mastery, mental models, shared vision, and team learning in organizations and its importance to corporate survival); Deanna J. Richards et al., *The Greening of Industrial Ecosystems: Overview and Perspective*, *in* THE GREENING OF INDUSTRIAL ECOSYSTEMS 1 (Braden R. Allenby & Deanna J. Richards eds., 1994) (giving overview of the concept of industrial ecosystems and applications of systems approach).

[15] David Thomas ranked the effectiveness of various policy and program approaches in promoting pollution prevention. He ranked direct regulation as highly effective, economic incentives as moderately so, and voluntary compliance and education programs as not very effective. DAVID THOMAS, ILL. HAZARDOUS WASTE RESEARCH AND INFO. CTR., INDUSTRIAL WASTE REDUCTION: STATE POLICY OPTIONS 154-56 (1990). Thomas predicted that the highest levels of pollution prevention activity will be found in facilities located in states that have mandatory reduction goals, impose taxes or fees on pollutants, and/or use a multimedia approach. *Id.*; *see also* TERRY FOECKE, WASTE REDUCTION INST. FOR TRAINING AND APPLICATIONS RESEARCH, PUBLIC EFFORTS TO PROMOTE POLLUTION PREVENTION: ARE THEY WORKING? 20 (1994) (concluding that most potential for promoting long-term organizational change lies in seminars and training, grants and loans, TRI data reports, cross-media coordination, and incorporation of pollution prevention projects into notices of violation and settlements).

For statutory models developed for use in the design and evaluation of pollution prevention planning statutes, see generally WILLIAM RYAN & RICHARD SCHRADER, NATIONAL ENVIRONMENTAL LAW CTR. AND CTR. FOR POLICY ALTERNATIVES, AN OUNCE OF TOXIC POLLUTION PREVENTION: RATING STATES' TOXIC USE REDUCTION LAWS (1991); Robin Sullivan & Donald Floyd, *Pollution Prevention Planning: An Analysis of Statutory Structure* issue of TAP effectiveness becomes even more complex as the focus of their activities shifts to larger, systemic issues.[16]

III. A SYSTEMS VIEW OF THE FIRM

A. SYSTEMS THINKING AND POLLUTION PREVENTION

Ultimately we desire policies and programs that address pollution prevention systemically, and we encourage industry to develop conceptually and organizationally to do the same. Roy suggests that policy makers and, by extension, program makers "view their task as one of creating heuristic devices both for the individual organizations involved in the pollution control debate and for society in general."[17] Systems thinking techniques allow us to conceptualize a model linking the decisions necessary for pollution prevention to the appropriate organizational and decision making characteristics in industry. Senge introduces systems thinking as follows:

> Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots." It is a set of general principles—distilled over the course of the twentieth century, spanning fields as diverse as the physical and social sciences, engineering, and management. It is also a set of specific tools and techniques,

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for Successful Policy Implementation, 13 ENVTL. PROF. 293 (1991).

[16] TAPs measure their effectiveness qualitatively by asking, "Did the customer value the service provided?" They also evaluate quantitatively in terms of reductions in wastes generated or released. The National Roundtable of State Pollution Prevention Programs "asserts that effectiveness evaluations of state pollution prevention programs must consider the mission of the program or program activity and the need to use new measures of effectiveness, that pollution prevention is a long-term process, and that much of the pollution prevention process originates in the private sector." GAO REPORT, *supra* note 13, at 49.

The GAO report concludes that "quantifiable amounts of reductions in wastes generated are required to ascertain the effectiveness of federal pollution prevention policy." *Id.*

[17] Manik R. Roy, How We Are Learning to Pollute Less: Pollution Control, Organizational Culture, and Social Learning 6 (1988) (unpublished Ph.D. dissertation, Harvard University).

> originating in two threads: in "feedback" concepts of cybernetics and in "servo-mechanism" engineering theory dating back to the nineteenth century. During the last thirty years, these tools have been applied to understand a wide range of corporate, urban, regional, economic, political, ecological, and even physiological systems. And systems thinking is a *sensibility—for the subtle interconnectedness that* gives living systems their unique character.[18]

Using Senge's systems archetypes for patterns of organizational behavior, we can group decisions into four categories: (1) product mix and characteristics, (2) product and process design to produce desired commodities, (3) product and process design in response to inefficiency, and (4) treatment and disposal of by products.[19] The

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[18] SENGE, *supra* note 14, at 68-69.

[19] *See also* Ann Rappaport & Patricia Dillon, *Private-Sector Environmental Decision Making, in* ENVIRONMENTAL DECISION MAKING 238, 239-42 (Richard Chechile & Susan Carlisle eds., 1991) (suggesting nine types of decisions: the product mix and characteristics, materials used in the manufacturing process, natural resources used, handling of byproducts, location of the company, facility design, accounting methods used, and company position regarding regulatory compliance). *See generally* PATRICIA S. DILLON & KURT FISCHER, ENVIRONMENTAL *MANAGEMENT IN CORPORATIONS (1992) (discussing environmental* management in corporations); PATRICIA S. DILLON & SARAH H. CREIGHTON, SURVEY OF ENVIRONMENTAL MANAGEMENT PRACTICES OF SMALL BUSINESSES (1993) (discussing environmental management in small businesses).

Many publications address the activities in the four decision categories. *See, e.g.*, DALE JAMIESON ET AL., CULTURAL BARRIERS TO BEHAVIORAL CHANGE (1993) (bibliography on conceptualization and cultural barriers to behavioral change for pollution prevention); THE NEW PARADIGM IN BUSINESS (Michael Ray & Alan Rinzler eds., 1993) (presenting wide variety of essays on emerging business views); James S. Bowman & Charles Davis, *Industry and Environment: Chief Executive Officer Attitudes, 1976 and 1986*, 13 ENVTL. MGMT. 2, 243-45 (1989) (reporting nearly three-fourths of respondents agreed environmental issues are important even when they slow new product introduction); Pierre Crosson & Michael A. Toman, *Economics and Sustainable Development, in* THE GREENING OF INDUSTRIAL ECOSYSTEMS, *supra* note 14, at 90 (discussing conceptual issues surrounding economics and sustainable development).

For more information on programs, policies, and approaches focusing on prevention, see BRENDA S. DAVIS & BARBARA M. GREER, POLLUTION PREVENTION: STATE POLICIES FOR INDUSTRIAL CHANGE (1993) (discussing state program issues); GAO REPORT, *supra* note 13 (same); ENVTL. PROTECTION AGENCY, EPA-100-R-94-002, EPA POLLUTION PREVENTION ACCOMPLISHMENTS: 1993 (1994) (summarizing activities promoting pollution prevention, *including internal organizational changes in Office of Enforcement, and state/local, private* sector, and federal partnerships); ENVTL. PROTECTION AGENCY, EPA-742-B-93-002, ONGOING corporation decides to manufacture goods or to provide services with certain performance characteristics in response to customer demands and needs. The decision to offer certain products sets boundaries for the product and process design decisions.[20] During implementation, the plant management and shop floor employees make incremental production decisions to optimize the performance of the selected technologies. If management succeeds, these conceptualization and achievement decisions result in a product the customer desires. The company finds itself in a *reinforcing cycle of growth*. This reinforcing cycle is shown in Figure 1.

EFFORTS BY STATE REGULATORY AGENCIES TO INTEGRATE POLLUTION PREVENTION INTO THEIR ACTIVITIES (1993) (reviewing efforts by state regulatory agencies organized by EPA region); NAT'L ADVISORY COUNCIL FOR ENVTL. POL'Y & TECH., EPA-100-R-93-004, TRANSFORMING ENVIRONMENTAL PERMITTING AND COMPLIANCE POLICIES TO PROMOTE POLLUTION PREVENTION (1993) (discussing comprehensively legislative, permitting, inspections, enforcement, and organizational issues promoting pollution prevention through regulatory process); Mickey R. Wilhelm et al., *Selection of Waste Management Technologies to Implement Manufacturing Pollution Prevention Strategies*, 2 INT'L J. ENVTL. CONSCIOUS DESIGN & MFG. 2, 41 (using fuzzy logic to evaluate qualitative attributes of pollution prevention strategies and to improve strategic manufacturing decision making).

[20] *See* NAT'L RES. COUNCIL, IMPROVING ENGINEERING DESIGN (1991) (finding quality of U.S. product engineering design generally poor and concluding that at least 70% of product development, manufacture, and use costs are determined during initial design process); OFFICE OF TECH. ASSESSMENT, U.S. CONGRESS, OTA-E-541, GREEN PRODUCTS BY DESIGN: CHOICES FOR A CLEANER ENVIRONMENT 1, 2 (1992) (recommending integrating environmental concerns into policies improving engineering design capabilities by requiring manufacturers to incorporate recycled materials into new products or to take back discarded consumer products, and by harnessing market forces (taxes or fees) to encourage manufacturers to make environmentally sound decisions); Braden R. Allenby, *Integrating Environment and Technology: Design for Environment*, *in* THE GREENING OF INDUSTRIAL ECOSYSTEMS, *supra* note 14, at 137 (discussing environmental design); F. Mistree et al., Decision-Based Design: A Contemporary Paradigm for Ship Design, Paper presented at the Annual Meeting of the Society of Naval Architects and Marine Engineers (Oct. 31 - Nov. 3, 1990) (on file with author) (discussing emerging design theory called "decision-based design," which incorporates systems thinking and current engineering concepts).

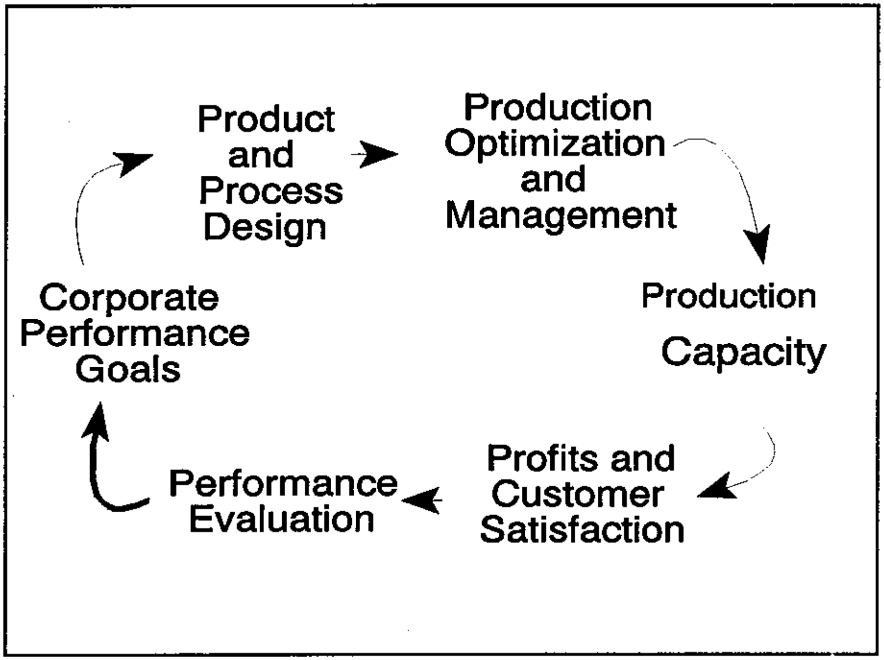

Figure 1

The strength of this growth cycle, however, is limited by a counterbalancing cycle. The growth cycle increases the availability of desired commodities. At the same time, it increases production of byproducts and wastes. Inefficient use of raw materials and energy yields a decrease in production and work and an increase in the cost of managing the resultant wastes. These wastes must be managed according to an increasingly complex set of environmental regulations. The growth cycle for a company today, therefore, is limited by efficiency. Thus, a *limits-to-growth cycle* dampens the growth cycle; that is, the resources required for waste management slow down the growth cycle. This *limits-to-growth cycle* is shown in Figure 2.

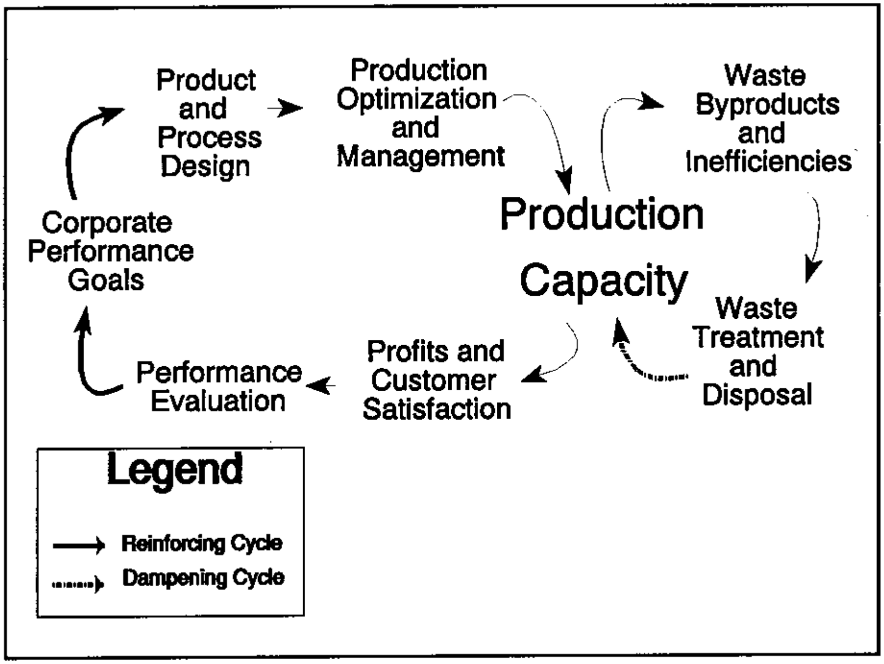

Figure 2

Two decision pathways exist for the long-term management of inefficiency and waste materials. On the one hand, managers can choose to continually treat and dispose of waste. This pathway externalizes the burden of residuals management to parties outside the firm, and it treats the symptom of inefficiency (i.e., the production of waste) rather than reducing the inefficiency itself. This option exposes the firm to impacts that can reduce profit. These impacts, however, are delayed. Impacts include: liability for toxic releases at disposal sites, community opposition to polluting production processes, increasingly stringent regulations, and decreased options for treating and disposing of wastes. Over time, these impacts can seriously threaten the profitability and viability of the firm. In the short run, however, they pose little threat.

On the other hand, managers also can choose to eliminate wastes by redesigning their products and processes. This solution internalizes the costs of the problem within the firm and eliminates the waste and inefficiency from the production process. However, pollution prevention requires considerable expenditures and managerial supervision with little immediate payoff.

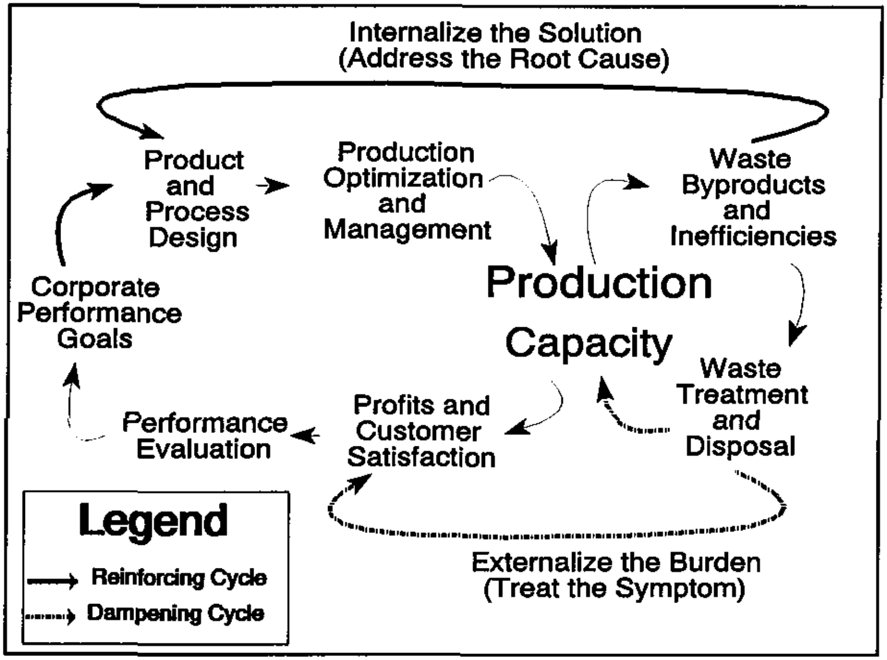

Figure 3

The system model in Figure 3 illustrates the connection between pollution prevention decisions and other managerial choices. A firm's ability to prevent pollution is limited not only by technological factors (e.g., applications of the laws of thermodynamics),[21] but equally by organizational factors. Environmental managers can

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[21] *See, e.g.*, Michael R. Chambers, *Planning for Technological Substitution and Change*, 25 INT'L J. PRODUCTION ECON. 191, 191-200 (1991). Chambers uses a systems analysis framework to identify technological substitution and change options in the chemicals, fuels, and energy sector in Australia. His model includes influences from national interests, corporate goals, societal needs, and environmental requirements. Chambers also emphasizes the importance of net energy analysis and economic analysis in identifying optimal change alternatives. *Id.* *See generally* Matthew Weinberg et al., *Industrial Ecology: The Role of Government*, *in* THE GREENING OF INDUSTRIAL ECOSYSTEMS, *supra* note 14, at 123 (emphasizing need for systemic approaches to environmental policy making).

make simple waste management decisions in isolation from other facility managers; however, as firms seek to reconceptualize waste management, decision making *must* become more integrated. The feedback loop located at the top of Figure 3 internalizes decision making and its consequences. Compare this to the feedback loop located at the bottom of Figure 3. The internalized (top) loop is organizationally more complex than the externalized (bottom) loop.

We can illustrate the difference in organizational complexity between the internalized (top) and externalized (bottom) loops through a transformation of the systems diagram shown in Figure 3. Consider the departments and individuals necessary to implement decisions made along each of the alternative waste management feedback loops. The top pollution prevention loop requires integration of environmental management with R&D, process management, operations, and maintenance divisions. Multi-unit, interdisciplinary teams are necessary to integrate these functions. The bottom waste management loop, however, externalizes the waste disposal and requires relatively little internal coordination.

The Complete Coating example further illustrates this decision making model. The TAP advises the company to progress up the waste management hierarchy[22] from disposal of paint-related wastes to product changes using alternative coatings. Decision making to support such progress requires a systemic approach that integrates evaluation and decision making across plant functions. Yet Complete Coating's organizational context and culture inhibits such integration. In this company, although the environmental manager is responsible for pollution prevention, she is unable to implement changes in products or processes. To understand the impact of organizational dynamics on pollution prevention, let us turn our attention to decision making in a corporation.

B. ORGANIZATIONAL DYNAMICS AND DECISION MAKING FOR POLLUTION PREVENTION

Decision making is limited by the bounded rationality of the decision maker who operates within both formal and informal

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[22] *See* 42 U.S.C. §§ 13101-13109 (1990) (codifying national policy of preventing and reducing pollution at source).

channels of communication in the organization.[23] Organizations face the problem of coordinating decisions that are separable into components where "the choice of an alternative can impose costs which are directly borne by other divisions or departments in the firm, and of which [the decision maker] has imperfect knowledge."[24] Deming illustrates this point quite well by showing how the components of a production flow diagram correspond to the typical organizational units in the company: corporate headquarters, departments for product and process design, research and development, production management, environmental management and worker health and safety, shipping, and sales.[25] The organizational units become competitive components whose independent goals destroy the systemic functioning of the manufacturing plant.[26] According to Deming, the role of management is "to recognize and manage the interdependence between components. Resolution of conflicts and removal of barriers to cooperation are responsibilities of management."[27]

The presence of a strong corporate culture "coordinates the bounded rationality of the members of the organization,"[28] reduces the costs of making decisions, and enables a firm to choose efficiently among alternatives. Two significant factors influencing a company's ability to make efficient, systemic decisions are its corporate culture and the characteristics of its communication and decision making style.

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[23] *See* Jacques Cremer, *Corporate Culture and Shared Knowledge*, 2 INDUS. & CORP. CHANGE 351, 360 (1993). Cremer argues that bounded rationality is a result of the following factors: humans are not perfect processors, acquirers, or transmitters of information; and humans are limited by the amount of knowledge they can acquire. He measures the cost of communication as the time spent transmitting and receiving information. *Id.*

[24] *Id.* at 365.

[25] W. EDWARDS DEMING, THE NEW ECONOMICS FOR INDUSTRY, GOVERNMENT, EDUCATION 60 (1993).

[26] *Id.* at 68.

[27] *Id.* at 65.

[28] Cremer, *supra* note 23, at 367 (defining corporate culture as "the part of the stock of knowledge that is shared by a substantial portion of the employees of the firm, but not by the general population from which they are drawn"). Roy addresses the role of organizational culture in a company's pollution-control related activities. Roy, *supra* note 17, at 4-6. He believes that pollution control policies intervene in organizational cultures, which he describes in terms of their norms, theories-in-action, symbolic languages, subgroup conflicts, and social network influences. Roy also asserts that organizations can learn from such interventions.

Regarding the influence of corporate culture in successful environmental management, one study found that the leadership of "progressive" corporations from corporate headquarters most often provided the driving force for environmental management initiatives at facilities.[29] These corporations also: (1) have environmental policies expressing corporate intentions, implementing requirements, and management directives that cover all significant environmental, health, and safety risks, whether regulated or not; (2) use management controls, which measure facility and individual performance against goals and standards, and provide formal environmental reviews for capital expenditures, new products, processes or materials, and property acquisition; and (3) use decision making tools, such as data collection and analysis systems and accounting methods.[30]

Another study proposes a relationship between a company's communication and decision making style and its environmental performance.[31] Companies with a dictatorial management style, poor interaction with the customer, and low morale are likely to have a history of compliance problems.[32] Companies can achieve compliance with a hierarchical management system that has departments operating independently;[33] however, to reach beyond compliance, companies generally need some element of participatory management and customer feedback.[34] Finally, an environmentally sustainable company uses a total quality management style, has multiple departments involved in decision making, is customer driven, pushes responsibility and authority to the bottom of the organization, and is capable of problem definition and solving.[35]

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[29] Rappaport, *supra* note 19, at 248.

[30] *Id.* at 252-57.

[31] A.J. Grant & Ellen Arnold, *Applying Total Quality Environmental Management to Midsize and Small Companies*, *in* CORPORATE QUALITY ENVIRONMENTAL MANAGEMENT III 89 (proceedings of Global Environmental Management Initiative Conference, Mar. 24-25, 1993).

[32] *Id.*

[33] *Id.*

[34] *Id.*

[35] PRESIDENT'S COMMISSION ON ENVIRONMENTAL QUALITY, TOTAL QUALITY MANAGEMENT: A FRAMEWORK FOR POLLUTION PREVENTION (1993) (linking use of quality management principles to significant pollution prevention and economic savings in numerous diverse demonstration projects). The Commission's report translates quality principles into an eight-step generic model used to identify pollution prevention options. *Id.*

Rappaport and Dillon concluded that successful companies recognize that business and production managers make decisions impacting the environment throughout the product life cycle.[36] They also found that the "formal organizational structure of the environmental function within the company hierarchy seemed to have little bearing on the performance and quality of environmental management."[37] The qualities of the environmental managers, their informal relationships, and "their political and communication skills"[38] were more important.

Note that the characteristics of successful environmental management are similar to Pearson's key characteristics for management of innovation: "the importance of observant people, the value of experience, the linking of different technologies to turn failure into success, the need for perseverance, the contribution of group problem solving techniques, the potential for opening up a wide range of opportunities and for changing, even destroying, existing organizational and market structures."[39]

Finally, corporate cultures are stable and resist selective intervention.[40] Greater flexibility in communication structures and mobility of employees leads to greater integration of corporate culture. "[P]rogressive reform by piecemeal improvement will be extremely difficult"[41] if not impossible.

IV. NEW TAPS FOR POLLUTION PREVENTION

A. POLLUTION PREVENTION IN MID-SIZED FIRMS

According to Kuhn, better performing mid-sized firms are flexible, entrepreneurial, and risk-taking in terms of their responsiveness to customer needs and their ability to make changes in their products.[42] He concludes that they are more innovative than

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36 Rappaport, *supra* note 19, at 251-52.
37 *Id.*
38 *Id.*
39 Pearson, *supra* note 12, at 20.
40 Cremer, *supra* note 23, at 377-81.
41 *Id.* at 379.
42 ROBERT L. KUHN, MID-SIZED FIRMS: SUCCESS STRATEGIES AND METHODOLOGIES 166-68 (1982).

larger firms and are distinctive in that they tightly define their products and dominate narrow markets.[43] They also have more financial and human resource constraints and are more dependent on external sources of information.[44]

All these characteristics would make us optimistic that mid-sized firms could effectively integrate pollution prevention efforts into their decision making. While many "better performing" mid-sized firms have done so, as a class mid-sized firms appear to develop less integrated solutions to pollution than do larger corporations.[45] Primarily facility managers and environmental specialists of mid-sized firms plan pollution prevention programs. When compared with larger corporations, these firms show a distinct pattern of between sixteen and twenty-eight percent less involvement by process and production specialists, corporate office staff, production line employees, and environmental specialists. While relatively few owners directly involve themselves in the planning of pollution prevention projects, mid-sized firms nonetheless have significantly greater owner involvement than do larger firms.

Mid-sized firms also appear to be more dependent on outside information sources than are larger firms. Mid-sized firms identify options for pollution prevention from a wide array of information sources. We asked mid-sized firms to list the three most important methods for identifying pollution prevention options. Over half of the firms surveyed listed the use of internal quality teams, self-initiated assessments, expressions of concern from state regulatory agencies, and published literature. Yet, when compared to larger firms, mid-sized firms show a clear dependence on externally generated methods for identifying pollution prevention options,

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[43] *Id.* at 21-23. Kuhn defines mid-sized firms as having total assets between $10 million and $500 million, total revenues between $10 million and $500 million, and total number of employees between 100 and 10,000.

[44] Erich Staudt et al., *Technology Centres and Science Parks*, 9 INT'L J. TECH. MGMT. 198 (1994).

[45] The description of mid-sized firms emerges from a study of about 600 firms conducted by the authors. The sampled firms were located in six states and were eligible for the EPA's 33/50 Program. The researchers sampled all firms with between 2 and 30 facilities and with greater than 100 and less than 1000 employees per facility. These firms were identified using data from the Toxics Release Inventory. A questionnaire was sent to each of the 1600 firms that met these criteria. Forty percent responded. Finally, respondents were classified as to mid-sized and large firms using economic data from Standard and Poor's.

such as published literature, trade associations, free outside assistance, and nonregulatory technical assistance programs. Consequently, the same firms under utilize internally derived methods of identifying P^2 projects; use of quality teams, self-initiated assessments, and employee recommendations was between eight and twenty-two percent less than for larger corporations. Consultants also are used less extensively by mid-sized firms.

When compared to larger firms, then, mid-sized firms' organizational and technological capacity is lower. Yet mid-sized firms, on average, appear to reduce almost as much pollution through pollution prevention programs as larger firms. Although figures varied widely among the firms studied, mid-sized firms reduced an average of 4.2 million pounds of waste through these programs; this amount was ninety-two percent of the average reduced by larger firms. Therefore, it would appear that considerable opportunity for pollution prevention technical assistance exists amongst mid-sized firms.

B. TRANSFORMING TECHNOLOGY TRANSFER PROGRAMS FOR POLLUTION PREVENTION

Policies and programs designed to promote pollution prevention often neglect the relationship between the nature of the action and the capability of the organization to act. Decision making in firms is multidimensional, but for pollution prevention, at least two dimensions appear to be significant. Technology transfer programs for pollution prevention need components that address the systemic nature of both the technological problem and the decision making structure, as illustrated in Figure 3.

Pollution prevention options that focus on root causes are more systemic in that they require concurrent adjustments in the design, production, and waste management components of the production cycle.[46] On the other hand, options focusing on waste management are less systemic, with impacts externalized outside the production system.[47] As the options become more systemic, the corporate culture and its communication and decision making must

[46] *See supra* note 22 and accompanying text (discussing upper loop of cycle in Figure 3).
[47] *See supra* note 22 and accompanying text (discussing lower loop of cycle).

adjust accordingly.

For example, a company with a dictatorial or rigid hierarchical management structure probably can solve compliance issues and may be able to effect some minor changes in operating practices. The environmental manager would carry primary responsibility for compliance and any changes made. However, it is unlikely that the hierarchical management structure, on its own, will make significant modifications in its products and processes solely for environmental reasons. Yet, the company may be able to reach farther up the pollution prevention hierarchy with the intervention of an external organization such as a TAP, vendor, or regulatory agency. As companies become more participatory, communication across departments is easier and more frequent, and problems can be framed more systemically.

Let us return to the hypothetical TAP case study discussed at the beginning of this Article. What role does the TAP play in the decision making processes of the companies it serves? The report it gave the company manager focused on a range of options from waste management to product redesign.[48] The process by which the TAP professional canvasses for possible options, both in literature and on the shop floor, and communicates those options to the top management becomes either a surrogate for, or a part of, multidepartmental, participatory decision making in the plant. Technical assistance "junkies" may be companies whose decision making structures are not conducive to systemic problem solving. In terms of measuring effectiveness, the TAP may be effective at solving a particular problem but ineffective at changing a company so that it can solve its own problems.

The findings of our study of mid-sized firms have three important implications for TAPs. First, mid-sized firms provide considerable opportunity for traditional TAPs. At the same time, these firms pose a considerable challenge to traditional modes of technical assistance because of their complex organizational structures, limited organizational and technological capacities, and potentially significant environmental impacts.

Second, a stronger relationship between the environmental TAPs

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[48] *See supra* note 22 and accompanying text (discussing waste management in lower loop of Figure 3 and product redesign in upper loop of Figure 3).

and the industrial management TAPs may be in order. To improve the quality of pollution prevention technology transfer, the TAPs should reorganize so that they can provide *technologies* (defined broadly) that: (1) improve companies' organizational capability to address problems systemically; and (2) help them systemically to reduce the environmental impact of their manufacturing practices. The technical assistance process could proceed as before, with the environmental TAP intervening in the decision making process to solve a particular problem, and a concurrent evaluation by the industrial management TAP of the decision making capability of the firm to identify the need for possible interventions. In the long term, the TAPs could become more interdisciplinary.

Third, TAPs will need an assessment methodology or diagnostic test to evaluate both the technological and organizational conditions in a company. The pollution prevention TAPs already have techniques for assessing the technological nature of a plant's problems; one possible tool for measuring organizational conditions is benchmarking. The TAP could facilitate benchmarking studies in an industry sector and use the information and the political strength of the "buy in" associated with such an approach to evaluate that sector's organizational and technological needs.[49]

In the end, new measures for the firm's organizational as well as technological progress will be needed to evaluate the effectiveness of technical assistance programs as instruments for promoting pollution prevention.

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[49] The Business Roundtable conducted an interesting benchmarking study of its pollution prevention programs. *See* BUSINESS ROUNDTABLE, FACILITY LEVEL POLLUTION PREVENTION BENCHMARKING STUDY (1993); *see also* DILLON & CREIGHTON, *supra* note 19 (finding that among small businesses, certain types of change are more likely in one industrial sector than another). Dillon and Creighton noted, for example, that process changes are more common in the chemical industry than in the metals industry. *Id.* These differences reflect important differences in technology and economics between industries. At the same time, they also reflect organizational responses to external and internal threats to the firms in these industries, and the efforts of the industries to coordinate responses to these threats. *Id.*