WORKING PAPER

INNOVATION FROM DIFFERENTIATION:
Pollution Control Departments and Innovation in the Printed Circuit Industry

Andrew King

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ABSTRACT

Organizational theorists, industry professionals and policy analysts predict that firms tend to respond to environmental regulation by creating pollution control departments to span the boundary between the organization and the surrounding society. Theory predicts that these departments will insulate the firm from changing conditions and either 1) cause continuance of efficient operations, or 2) prevent adaptation to new conditions. In an empirical study, I find that in some firms pollution control departments act not as insulators, but as information and innovation conduits, and thereby help improve the production process. I find that pollution control departments have access to unique data from inside and outside of the organization, and that this information derives in part from their specialized role. Thus, I propose that organizations that have boundary-spanning units and allow these units extensive communication with the rest of the organization have the highest performance relative to both existing (i.e. cost and quality) and new (i.e. environmental) criteria.

INTRODUCTION

Many companies now face challenges of both tougher global competition and more stringent requirements to protect the natural environment. Some firms like Union Carbide have responded by creating separate departments and functions to mediate between the firm and environmental regulators, while others like 3M and DOW Chemical have attempted to integrate pollution control responsibility into existing organizational roles[1-3]. Theory suggests that these two approaches present a dilemma: a separate department allows scale efficiencies, controlled risk, and efficient production, while an integrated approach allows the firm to learn and adapt to new conditions[4-7]. Whatever their view of the effect of such departments, these theories predict that most firms will respond to changing environmental conditions by forming specialized pollution control departments, and that once created, these departments will have little interaction with the rest of the firm and little role in process innovation[4, 7, 8].

This paper investigates the role of pollution control departments in information transfer and process innovation. The twelve printed circuit fabrication firms studied all responded to increased regulation by creating organizationally separate pollution control departments, and these departments reported initially having little interaction (measured as communication) with the rest of the organization. In spite of these initial relations, over time some pollution control departments came to interact frequently with the rest of the organization. These pollution control departments often provided information and innovation ideas to process engineers that resulted in process improvement (relative to cost, quality and capability). Pollution control departments were able to make these process improvements because they had unique information, and that this information derived in part from their specialized role. Finally, I propose that a balance between separation and integration may lead both to better process performance (cost and quality) and to better environmental performance.

THEORETICAL BACKGROUND

Pollution control departments span the boundary between the organization and its surroundings. Organizational theory provides four main perspectives on the effect and behavior of such boundary-spanning departments. Thompson [4] claims that such departments allow organizations to remain efficient in the face of changing business conditions, while Burns and Stalker's work [5] suggests that such organizational structures may reduce adaptability. Proponents of "lean production" or "total quality" argue that such departments reduce information flow and thus impede performance improvement [7-9]. A fourth perspective emphasizes the potentially divisive effects of differentiated boundary-spanning departments, and thus the need for integrating mechanisms [10].

The first perspective on the role of specialized boundary-spanning departments draws upon the long history of theories of division of labor and efficiency [11-13]. These theories assume that focussed application of skill and technology best leads to efficiency and learning [11, 13]. In this view, lateral interactions between tasks or departments require application of scarce coordination resources and distracts attention from optimizing the task at hand[4, 14]. If changing conditions (such as increasing environmental regulation) require the firm to create new tasks to address new conditions, these tasks should be separated from the existing firm so as to prevent disturbance the production process (which is assumed to be optimized). Thus rational firms seek "to isolate their technical cores from environmental influence by establishing boundary-spanning units to buffer or level environmental[1] fluctuations [4 pg. 67]." Once these departments are created, organizations attempt to minimize information processing costs between boundary-spanning departments and the core [4, 14-17].

The second perspective extends the above ideas to include the importance of adaptation. Burns and Stalker [5] argue that in changing conditions, reduced specialization and increased lateral communication allow 1) recognition of new conditions, 2) more rapid change of objectives and 3) the acquisition of new capabilities. In stable environments, however, Burns and Stalker share the perspective presented above that lateral communication patterns and task integration raise communication and coordination costs and do not better facilitate performance improvement[5]. Thus, Burns and Stalker's theories suggest that interaction between pollution control departments will improve adaptation to new conditions (pollution control), but will have no positive effect on the production process relative to existing and stable criteria (quality, cost etc.).

A third perspective on pollution control departments arises from proponents of "quality" and "lean production". Unlike Thompson[4], Galbraith[14] and even Burns and Stalker[5], who assume that efficiency arises from the focussed application of specialized skill and technology, proponents of "quality" or "lean production" assume that efficiency results from the broadening of incentives and lateral exchange of information [7, 8]. This can be accomplished, they claim, only when responsibility for tasks (such as quality and pollution control protection) is distributed throughout the company. When this is done, workers have both broad incentives and the ability to transfer relevant information [8 pg. 99].

The "quality" movement has had the greatest influence on industry managers and policy analysts. Bemoski[18], Thomas[19], Martin[20] argue that pollution control and quality departments have analogous roles in the organization. Therefore, they expect pollution control groups to buffer the firm from a changing environment, delay and filter feedback information, and prevent core-process adaptation [3, 21]. The Congressional Office of Technology Assessment, in its seminal report Serious Reduction of Hazardous Waste, argues that pollution control departments will insulate the firm from environmental requirements, and consequently prevent core-process change that might reduce the production of hazardous waste[22].

While "quality" theorists and industry analysts propose that separate pollution control departments will impede information transfer and learning, they agree with Thompson [4] that firms will respond to changing environmental conditions by creating such departments, and they expect the relationship between these departments and the rest of the organization to be distant[23]. In part for this reason, government has begun to create legislation that "does not stop at the boundary of the firm", but requires the adoption of pollution control accounting and control practices throughout the firm[24].

The fourth organizational perspective, that of Lawrence and Lorsch[10], differs from the above theories in that it emphasizes intergroup conflict in organizational analysis rather than tradeoffs between specialization and information transfer. Lawrence and Lorsch[10] argue that precisely because boundary-spanning departments mediate between the organization and different surrounding

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[1] Thompson did not, of course, mean to indicate only the natural environment, but the general conditions surrounding the firm.

institutions these departments develop differing goals, time perspectives, interpersonal orientations and formality of structures. These differences then cause conflict between groups which must be offset through the use of integrative devices (such as meetings and teams)[10 pg. 12]. They found that in changing and/or uncertain environments, firms that simultaneously had highly differentiated departments and appropriate integrative mechanisms performed best.

In the remainder of this paper, I outline several hypotheses consistent with the above theories, and attempt to validate them by looking in one industry at the behavior of boundary-spanning departments that firms created in response to environmental regulation. I show that the above theories do not accurately predict the extent, nature or implications of interaction between boundary-spanning departments and the organizational core. I then develop a theory that might explain the behavior of the firms in my sample.

HYPOTHESES

Thompson predicts that, when faced with changing external conditions, rational organizations establishes separated boundary-spanning departments to mediate between the firm and its surroundings. Piore and Sable[6], MacDuffie[7] and Womack, Jones and Roos[8] also anticipate that U.S. firms will respond to changing surrounding conditions by creating such boundary-spanning departments. Once created, Thompson[4], Galbraith[14], MacDuffie[7] and Womack, Jones and Roos[8] predict that relations between these departments and the rest of the organization will be distant. Thompson[4], Galbraith[14] predict that interaction with such departments will relate predominantly to issues of task coordination. Thus, my first two hypothesis are:

Hypothesis 1: Pollution control departments will be created to insulate the firm from threatening environmental conditions (new requirements).

Hypothesis 2: a) Interaction between pollution control departments and the organizational core will usually be limited.
b) What interaction occurs will relate to environmental issues.

Thompson[4], Galbraith[14] both predict that rational organizations form boundary-spanning departments to insulate the organization from distracting surrounding conditions. Thus, my third hypothesis is:

Hypothesis 3: a)Interaction between pollution control departments and the organizational core will be associated with process innovation that improves environmental performance.
b) This same interaction will result in process innovation that reduces core performance. Thus, in high performing firms (low cost, high quality) pollution control departments will have little interaction with the organizational core.[2]

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[2]It might also be possible to form an alternative hypothesis from the quality literature that interaction with the environmental department will be associated with process innovation that improves both environmental performance and core performance. This literature generally assumes, however, that such communication is unlikely[8].

EMPIRICAL RESEARCH

The Research Setting

The printed circuit fabrication industry is a rich domain in which to study the behavior of pollution control departments. Since the early 1980s, printed circuit firms have faced stringent regulation of the discharge of metals and organic compounds. Moreover, the industry includes many companies that use similar technology to produce commodity products, thus allowing cross-firm comparison of performance.

All of the twelve plants in my study produce multilayer rigid printed circuit boards. All of the companies make medium complexity boards for the computer industry, and fewer than 10% of their production volume (measured in panels) is of high complexity[3]. Firms vary in size from $5 million to more than $200 million in annual sales. Most of the firms are privately held and have a single production facility. Two have multiple production facilities, and two are part of computer firms. Plant production varies from $5 to 50 million in sales.

Qualitative Research Method

To understand how printed circuit board (PCB) fabricators have responded to these new requirements, I began with open-ended interviews of firm presidents, plant managers, process engineers, quality personnel and pollution control personnel. To focus the field of inquiry, I concentrated on the etching and plating part of the production process - usually known as the "wet-process". Engineers responsible for this part of production are called Wet Process Engineers.

After several exploratory interviews, I developed a procedure of entering a plant, inquiring about the history of the plant and organization, and then walking through the plant with staff from the departments of wet process engineering (WPE), quality and pollution control (PC). In each of these tours, I asked that major process changes be identified. I also developed a list of improvement areas about which I asked probing questions to determine if some potential improvements had been recognized or exploited.

Qualitative Findings

Early in my investigation, I found support for the hypothesis that firms will create specialized departments to respond to changing conditions (Hypothesis 1). All of the eight firms visited had purchased waste filtration equipment, and all of the firms had formed a pollution control department which was organizationally separate from engineering or operations. According to pollution control (PC) managers, all of these groups were intended to protect the firm from regulatory problems.

Although all of the pollution control departments had similar mandates, I found behavior that seemed to contradict the hypothesis that communication between these specialized departments and the organizational core would be limited (Hypothesis 2a). While in about half of the firms PC personnel reported conversing seldom with wet process personnel, in the other firms they judged such conversations to be frequent. Three classes of behavior for pollution control departments emerged(figure 1).

My qualitative evidence also contradicted the hypothesis that interaction between pollution control departments and the organizational core would lead to reduced performance (Hypothesis 3b). In discussions with wet process and pollution control managers, I learned that pollution control departments often had information important to improving the production process in areas unrelated to environmental protection. Thus, when WPE managers acquired this information, substantial performance improvement could result. In one firm, PC personnel had initiated innovation that, over one year, caused a 41 percent reduction in the use of process materials (an annual saving of $113,000 or about one percent of sales).

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3 Defined as 1) density of three traces between 0.100" centers, or 2) surface mount with fine pitch applications.

Figure 1
Classes of Behavior for Pollution Control Departments

Description	**Number of firms in class**
A) The Buffer: The Pollution Control department insulates the production process from regulatory change by treating waste. PC personnel inform the organization of environmental regulations and get involved in production issues only when treatment or health issues arise. Quote: "We (Pollution Control) should stay out of process procedures."	4
B) The Feedback Buffer: The Pollution Control department insures that the firm is in compliance by treating waste, but it should not have to treat waste unnecessarily. If a problem occurs in production, PC personnel pass relevant data to production concerning water flow, chemical composition and so forth. Quote: "If something goes wrong, we (Pollution Control) let them know about it."	2
C) The Information Conduit: The Pollution Control department attempts to reduce waste as well as treat it. PC personnel frequently pass information on performance, problem areas and solution ideas to process engineers. Quote: "They (PC personnel) are like a second pair of eyes and ears for me (the process manager)"	2
	Total of 8 firms visited

Quantitative Research Method

I designed my quantitative research to measure the extent, nature and effect of interaction between PC departments and core process personnel so as to validate my qualitative evidence that contradicted Hypotheses 2 and 3. Twelve rigid printed circuit firms agreed to participate in the study and were sent questionnaires for the wet process, quality and pollution control managers. Eight firms returned all three surveys, two returned two surveys, and two did not respond. I also sent performance surveys to the twelve firms with questions on quality, production cost, and treatment cost. I received responses from nine.

Measuring Interaction

To measure the nature of interaction between functional groups, the survey asked managers of the wet process , quality and pollution control departments to characterize both their own and their compatriots behavior. The survey asked questions about time spent communicating with personnel from other departments in the firm, the nature of interaction and the topics discussed.

Measuring Process Innovation

The managers of wet process engineering, quality and pollution control were asked to report the five most important process changes that occurred in the last year and to rate the members of each of the three groups in terms of their role in 1) "identifying the opportunity or need that became the impetus for the change" and 2) "in designing the change". The managers were then asked to indicate the effects of these process changes. Respondents could choose one or more of the following options: improve product quality, improve production capabilities, reduce production costs, improve pollution control, or other/don't know.

Firm Performance

The performance survey dichotomized the production of the firms into boards of unusual complexity, and those that were commonly produced at all of the firms. It then measured yield rates at several stages and the cost of materials used in production and in treatment. [Because of differences in cost tracking methods at the firms, I was unable to use the responses on cost of production materials.]

Quantitative Findings

Interaction between Pollution Control and the rest of the firm

Contrary to Hypothesis 2a (pollution control departments will seldom interact with the organizational core), my data indicate that pollution control (PC) personnel interact extensively with the rest of the organization. WPE managers reported speaking more often (though not significantly so) to PC personnel than to maintenance, management, purchasing, or other engineering personnel (usually dry process engineering). Moreover, despite the current importance of quality in the industry, PC and quality managers do not differ significantly in total time spent communicating with the rest of the organization (figure 2). Quality managers did differ significantly in time spent communicating with "production personnel" and "management". This may be caused by management concern about quality and by the direct role quality managers often play in certain functions in production (e.g. automatic optical inspection).

Figure 2

Time spent by Quality and Pollution Control Managers communicating with the rest of the organization

Communication to	PC Communication (hrs/week)			Quality Communication (hrs/week)			Test of mean Difference	
Group	N	Mean	Std.Dev.	N	Mean	Std. Dev.	T	Prob
Wet Process	8	3.22	2.81	7	2.86	1.35	0.17	0.87
Laboratory	5	1.3	0.837	5	1.20	0.70	too few cases*	
PC	NA	NA	NA	6	0.96	1.61	NA	NA
Quality	6	1.04	1.05	NA	NA	NA	NA	NA
Maintenance	8	2.66	3.80	5	1.1	1.03	1.39	0.24
Purchasing	8	1.19	0.651	5	1.3	0.91	0.19	0.86
Production	7	4.25	2.64	7	9.29	7.20	2.2	0.08
Management	7	1.36	1.65	6	5.33	3.01	3.42	0.03
Total Time	9	12.7	8.65	9	17.7	14.2	0.99	0.35

*degrees of freedom < 4.

The data also indicate that conversations with PC personnel frequently include topics other than pollution control(in contrast to Hypothesis 2b). While both pollution control and wet process managers reported conversations about "waste treatment" as "very common", conversations about "waste of material in production" were reported by both as "common" . PC managers reported that their own conversations with WPE personnel commonly included discussion of "quality" and "yield".

Pollution Control Interaction and Process Innovation

If interaction is measured by the effect of a department on core technology, the data again show that PC personnel are interacting with the organizational core(in contrast to Hypothesis 2a). WPE managers rated their own personnel as most important in initiating and designing process changes (see figure 3), but judged quality and PC personnel to be of nearly identical importance in initiating process changes.[4]

Remarkably, in two firms the Wet Process Engineering Manager rated PC personnel as more important on average than his own staff in initiating reported process changes .

Figure 3

Wet Process Engineering Managers Ratings of Importance of Personnel of Different Groups in Initiating Most Important Process Changes in Previous Year

Group	Mean Rating of Importance	Std. Dev. of rating	N Firms	N Process Innovations
PC	0.99	0.72	8	33
Quality	1.193	0.59(.23)*	8	33
WPE	1.45	0.51	8	33

Anova for blocks: $F_{block} = 1.77$; $F_{group}=0.76$; $Df_g = 2$; $Df_b= 7$; $Df_e =14$; $p_b = 0.8$; $p_g = 0.47$

Scale: 0 = not at all important, 1 = important, 2 = very important.

* Std. Dev. with one firm removed.

Pollution Control Interaction, Process Innovation and Firm Performance

Hypothesis 3a predicts that pollution control interaction with the core production process will be associated with process innovation that leads to improved environmental protection. The data support this hypothesis. As reported by the wet process manager, communication time with pollution control personnel was associated with PC initiated process innovations (Kendall's Tau $t = .62$ $p < .1$), and 80% of these changes resulted in pollution reduction.

In contrast to Hypothesis 3b, the data also show that PC initiated innovation often led to improvement of the production process relative to core objectives. PC initiated innovations were as likely to lead to cost reduction as pollution control, and often resulted in quality improvement. Out of 33 reported innovations, PC personnel received the highest importance rating for 13. Of these, 11 resulted in pollution reduction, 12 in cost reduction, eight in quality improvement, and five in extension of production capabilities.

Preliminary data from five firms indicate that, in contrast to Hypothesis 3b, interaction between pollution control and process engineering departments may improve the performance of the core-process. Two firms that reported PC initiated quality innovation, had higher first pass yields for etched layers (an important measure for quality) than did the two firms reporting no PC initiated quality improvements. Likewise, WPE managers reported discussing quality (along with other non-pollution control topics) with PC personnel more frequently in three firms with high quality, than they did in two firms with low quality (as measured by first pass yields for etched layers).

[4]Data about process innovation from the three managers exhibit a substantial respondent bias. All three managers tended to report innovations in which their own personnel played a key role. Since WPE managers can best judge innovations in their department, and likely will underestimate the role of other departments, I concluded that WPE manager reports of innovation would be both conservative and accurate.

Pollution Control Departments as Sources of Important Information

As predicted, firms did indeed form boundary-spanning (pollution control) departments to buffer themselves from changing regulatory requirements. However, contrary to expectations, these departments had extensive interaction with the core of the firm, and this interaction was correlated with performance improvement with regard to both environmental protection and core-performance.

One might argue that such behavior might be the result of underlying firm characteristics that really caused the changes in innovation and performance. For instance, pollution control communication rates could result from an "organic" organization where lateral communication is emphasized. Alternatively, pollution control personnel might have unusual individual characteristics (e.g. better education, or more recent exposure to another company). The data do not show evidence, however, that the WPE-PC communication patterns result from individual or firm level characteristics. Organizational levels of communication, as estimated by the wet process and quality managers are not correlated with the volume of communication between the WPE manager and PC personnel (figure 4). Nor is the total time wet process and PC managers spend communicating with the rest of the organization correlated with how often they communicate with each other (figure 4). Additionally, PC managers had somewhat shorter tenure in the firm (3.9 to 6.8 years), but longer job tenures (3.5 years as opposed to 1.9)[Neither difference is significant at $p < .1$]. Three PC managers reported obtaining chemical or chemical engineering degrees, while six WPE managers reported having chemical engineering degrees.

My research suggests that pollution control managers, rather than inhibiting process improvement, actually can provide useful information and support. My quantitative data show that it was not communication per se, but communication about certain topics that led to innovation initiated by pollution control personnel. Communication about topics outside of the normal purview of pollution control best explained PC initiation of process innovation. Two breadth measures comprised of 1) quality and yield related topics and 2) scrap and efficiency topics, both correlate strongly with PC initiated innovations (figure 4). Likewise breadth correlates with communication time, and communication time correlates with PC innovation. The partial correlation between breadth and innovation, controlling for communication time is still high ($t = 0.70$). The partial correlation between communication and innovation, however, is much lower ($t = 0.34$).

The clear correlation between the breadth of conversation topic and communication could suggest either that frequent communication leads to a broadening of discussion topics, or that knowledge about a variety of topics encourages more frequent communication. To further explore this relationship, I constructed a scale of PC "information helpfulness" from reports of 1) PC frequency in requiring (for pollution control reasons) process changes and 2) PC frequency in providing process improvement information.[5] I hypothesized that pollution control departments that were more likely to provide useful information as opposed to new demands would encourage greater communication with WPE personnel. As predicted, this scale is correlated with PC-WPE communication volume($t =.65$, $p <.05$).

The above quantitative evidence closely matches observations from my qualitative study, when I often observed PC personnel passing non-pollution control information to process engineers. Likewise, process engineers frequently asked pollution control personnel for information on production chemicals or problems.

Thus, I believe that pollution control departments actually have unique and important information that can be used to improve the core of the firm. When, as my data show, process engineers tap this resource, core process improvements result. Such a claim leads to an obvious question: Why do pollution control departments have information that is useful in improving the production process?

My research uncovered several explanations.

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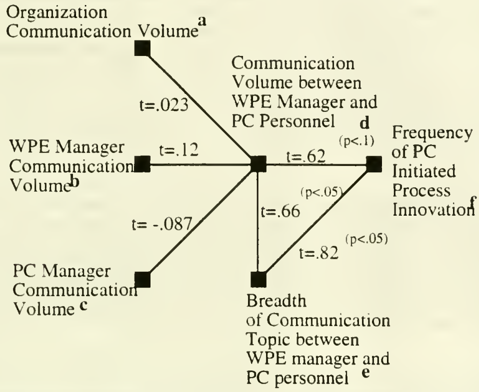
[5]The scale was constructed by subtracting scores for frequency of requiring change from frequency of providing helpful information.



NOTES

a - hours/week spent by Quality and WPE managers communicating with people outside of their own group other than PC personnel
b - hours/week spent by WPE manager communicating with non-PC personnel outside his department
c - hours/week spent by PC manager communicating with non-WPE personnel outside of his department
d - hours/week spent by WPE manager talking to PC personnel
e - breadth measure composed of Likert frequency reports of conversations about quality, yield, tracking and process control.
f - WPE manager reports of PC involvement in initiating process innovation

Figure 4 - Paired Kendall Tau correlations between communication measures and PC initiated process innovation.

Sources of Pollution Control Information

Difference of perspective

Pollution control personnel work in a forgotten part of the production process. They are concerned with discarded material, byproducts of the operation, mistakes and waste. In my qualitative study, I found evidence that pollution control personnel bring a different perspective to production problems. The qualitative data also supports this: PC and WPE managers disagreed on the frequency with which they discussed certain topics with personnel from the other department (Figure 5).

Figure 5

Comparison of PC and WPE Reports of Discussion Topics with Personnel From the Other Group.

Topic	Mean Difference Between Reports	Std. Dev.	DF	Prob
Quality	-0.72	2.08	8	0.33
Yield	-0.39	1.50	8	0.46
Waste of material in production	0.17	1.77	8	0.78
Scrap	0.056	1.18	8	0.89
Waste treatment	0.89	1.05	8	0.035

The data suggest that WPE managers classify some conversations as pertaining to waste treatment that pollution control managers interpret as pertaining to quality or yield. To understand why this might be true, I called wet process engineering managers, quality and pollution control managers at several firms and talked to them about their definition of the above terms. Widely different definitions appeared. The wet process and quality managers defined yield as the number of circuit layers that passed the electrical test divided by the number processed. Quality was defined as the performance of the board when used by the customer. pollution control managers, on the other hand, had a much broader definition of yield that included efficiency in the use of chemical materials, copper anodes, and cleaning material. Quality was an amorphous measure that included the role of a "quality" etching bath and cleaning tanks in producing a "quality" product.

Downstream Feedback

Pollution control departments receive output from every production process in the plant. From the wet production process it receives both a continuous flow of effluent and discrete "dumps" of used chemical baths and scrapped solid material. In all of the firms that I visited, PC managers knew that this waste could be used to diagnose problems in the upstream process. Most commonly PC personnel told me that if the water in the treatment process turned blue it meant that chelate copper was leaking from one of the pumps in production. Since most companies process their cleaning water continuously, PC personnel must mindfully respond to process variation and thus may be unusually aware of production performance.

Waste provides diagnostic information

The waste stream also provides more than anomaly information. Just as a urinalysis provides rich information about human health, production waste provides extensive information about the health of the production process. More than many process signals, the waste stream carries information about the location and cause of process inefficiencies. For instance, at one firm, pollution control engineers noticed that they frequently received stacks of discarded boards that had been partially etched and plated but not electrically tested. Pollution control personnel investigated and found that the plating operation performed best when the hoist contained a full load. To insure the best performance, the ends of production jobs were padded with extra boards to the nearest full load. Extra boards were then discarded. Wet-process and PC personnel designed a system of reusable dummy boards. As a result, the firm avoided discarding 5,000 boards per year at an estimated value of $25,000 (0.25 % of sales).

Pollution control has access to information about the entire system

The pollution control staff are unusual in that they have a system-wide perspective of the production process. They gather data in the form of waste from many stages of production that may cross regions of authority and technology. For instance, at one local firm, the PC personnel noticed that several different groups (the chemical lab, production and lithography) would discard out-of-date chemicals of the same type at approximately the same time. Moreover, they noticed that the supply of these chemicals in the stock room fluctuated widely. They investigated and found that simultaneous orders to replace production stock from separate production centers gave purchasing an incorrect impression of increased demand, which in turn caused an overly large order and an increase in the stockroom inventory. To solve the problem, the PC engineers developed a computer tracking system and a purchasing projection system.

Pollution control access to outside information

Pollution control engineers have unique opportunities to access information from outside of the company. In some cases, regulation causes them to gather and store particularly detailed technical information. Even where unregulated, the rapid pace of technological change causes PC personnel to interact with outside vendors. In addition, PC personnel have unique access to information from chemical vendors. As one person put it: "When production calls up a vendor they get connected to sales, when we call up we get connected to the lab. They know that we have to know what is in it [the vendor's product] in order to treat it."

Pollution control personnel also engage in "know-how" trading of information with competitors and suppliers of chemicals. Vendors arrange tours of interesting waste treatment processes, and many firms welcome visits of waste treatment processes from other companies. In Massachusetts, local pollution control managers are now forming an informal association that will meet monthly to discuss technical issues.

Pollution control has motivation to improve the production process

Managers of pollution control departments claim that they can improve their own performance by improving the core process. For instance, one argues that "almost anything that I can do to help the production process helps me[to treat waste]." Another argues, that "the more I can get the process under control, the better I can reduce waste treatment." Thus, some PC managers believe that they can improve their own performance by reducing waste generated in the production process and by reducing swings in production performance. Thus, PC managers have created tracking and control systems for production baths, and automated purchasing and inventory systems. Such systems allow PC managers to more closely optimize their own treatment process. Not surprisingly, the three PC departments with the lowest treatment cost (dollars spent on treatment per board ft. of etched layers) were more involved in process innovation than two with higher costs.

IMPLICATIONS OF THESE RESULTS

My research suggests that pollution control departments, in the course of conducting their work, acquire information and innovation ideas that can be useful to the rest of the organization. When they communicate this information, performance improves relative to existing (cost, quality etc.) and new (environmental performance) criteria. My research supports the general findings of Lawrence and Lorsch[10] that high differentiation and high integration lead to high performance in changing environments, and extends their analysis beyond the context of inter-group conflict to include inter-group communication and innovation. It suggests however that specialization and differentiation need not lead to conflict, as Lawrence and Lorsch[10] assume, but can cause a kind of organic solidarity based upon expectations of mutual benefit[26]. Thus, integration may not require managerial support, but may arise naturally as different departments seek to gain access to useful information and innovation sources.

My findings contradict the expectations of Thompson [4] that boundary-spanning units best facilitate performance by insulating the core of the firm from environmental change. They also contradict the predictions of Schonberger [9] and Jones,Womack and Roos [8] that improvement and learning only occur when responsibility for boundary-spanning activities is integrated into the organization. This last claim exposes, however, a vexing Catch 22. Some might argue that a department is differentiated only so long as it is insulated from the rest of the firm, as soon as it is relates in any way to the rest of the firm, it is integrated.

I believe that this Catch 22 obscures the most important implication of my research. My research suggests that organizational choice for firms is not merely between differentiation and integration but between the paths to these two options. I claim that in the case of PC departments, differentiation and specialization allowed the acquisition of unique knowledge. My findings of differentiation leading to new perspective and new information are consistent with the findings of numerous researchers about implementation of *particular* process innovations[15, 27-29]. In the case of pollution control departments, differentiation led to information about *a class of innovations*. The need for this information then caused some PC departments to become information resources for the core process of the firm. Just as Kazanjian and Drazin [29] and Tyre [27] suggest that separation and then reintegration of an innovation project leads to better innovation, I suspect that immediate integration of pollution control tasks throughout the firm would have prevented this accumulation of specialized information, perspective and skill and thus inhibited innovation.

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