

Control Theory:
Why Pollution Control Technologies Have Failed to Keep Pace

A Thesis
submitted to the Faculty of the
Graduate School of Arts and Sciences
of Georgetown University
in partial fulfillment of the requirements for the
degree of
Master of Arts in
Communication, Culture and Technology

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Washington, DC
April 21, 2008

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ABSTRACT

Pollution is detrimental to the well-being of society and to the health of the environment. Given the high cost of waste it seems paradoxical that society continues to produce enormous amounts of it while failing to develop adequate pollution controls. To gain a more fundamental understanding of this seemingly paradoxical situation it is necessary to look at how living systems operate. Accordingly, this paper looks at the role information processing and reciprocal communication play with respect to the development of pollution control technologies. To do so, this paper builds from James Beniger's (1986) theory of control, where control is defined as "purposive influence toward a predetermined goal" (p. 7) and *information processing* and *reciprocal communication* are integral to the task of establishing control. As applied to this paper, it stands to reason that if control failed to develop in the area of pollution control then it might be due, at least in part, to a lack of information processing and reciprocal communication in that area.

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Chapter 1 - Introduction

Waste, in one form or another, has been around since the beginning of man, it is a natural part of the bodily process and the earliest attempts at material production. For as long as people have been creating waste they have been searching for ways to control and dispose of it. During the industrial revolution factories were built along rivers not only to take advantage of water power, but so that waste could be released into the water and washed downstream –out of sight, out of mind. While some methods of controlling waste remain as primitive as storing waste in a confined location and building a mound of earth around it (e.g. landfills), society has greatly improved its capacity for controlling waste and its related environmental pollution.

Despite advances in environmental protection laws, green technologies, and public awareness of pollution's effects, the world remains woefully polluted. According to Bernie Fischlowitz-Roberts of the Earth Policy Institute, air pollution in the United States contributes to some 70,000 excess deaths each year, while traffic fatalities claim 40,000 lives each year (Fischlowitz-Roberts, 2002). Chemical pollutants are found in all of America's major surface waterways and underground aquifers, and approximately 25% of the nation's population lives near a toxic waste site (Blatt, 2005, p. 65).

Waste is commonly understood to be any substance or article that requires to be disposed of. This means that waste is the only product of society that is not created for the specific purpose of fulfilling a goal. One could argue that waste is goal oriented because its production is necessary for the completion of certain tasks. For example, in order to produce heat from burning wood carbon dioxide must be created. However, the goal is to accomplish an explicit task using heat (create warmth, cook food). Since wood

is burned to create heat, which in turn is used to accomplish the task, fire and heat generation are the goal oriented products. Carbon dioxide is a by-product of the fire's production and serves no purpose towards completing the task so it is considered non-goal orientated.

An interesting paradox arises when looking at waste and its connection to society. First, waste is an undesirable product of society that serves no purpose. Second, failure to properly control waste results in pollution, which is detrimental to the well-being of society and to the health of the environment. Given the high cost of waste it seems paradoxical that society continues to produce enormous amounts of it while failing to develop adequate controls. Waste represents both a cost and a process inefficiency, with potential savings available for avoiding or minimizing waste. To gain a more fundamental understanding of this seemingly paradoxical situation it is necessary to look at how living systems operate. And by looking at living systems, it can be argued that waste production and its necessary control are unavoidable paired realities.

Living Systems and Waste

Living systems are material processors. They are designed to take in and process energy in order to sustain themselves. The idea of living systems as material processors can be applied at the micro level to an individual cell in an organism and at the macro level to an entire ecosystem. Society can be viewed as a complex living system, one that sustains itself by controlling the flow of matter and energy into and through society. In fact, when looked at as a processing system, society appears very adept at controlling the extraction and processing of raw materials into consumable goods, storing and transporting those goods, and facilitating the consumption of those goods.

Describing life systems, James Beniger (1986) notes that society continually evolves to maintain control over the tremendous flow of matter required to maintain the system. The continual evolution in control over system processes occurs because, as a living system, society is subject to the scientific laws that govern living systems (Beniger). Accordingly, the rules governing the internal workings of a system dictate that advances of control in one part of the system require advances of control in other parts of the system—the need to maintain control is so that the system can maintain itself counter to entropy, which is part of the second law of thermodynamics and will be covered more in chapter two. Beniger believes that this process creates a “dynamic tension between crisis and control” (p. 220) because each success at control generates a new need for additional control. The result of the dialectical relationship between crisis and control is a social processing system that has evolved to control the “extraction and processing of matter, its internal distribution and storage, continuous conversion into energy, and elimination as by-product wastes” (Beniger, p. 37).

The above idea can be easily demonstrated using historical events as the basis of reasoning. For example, success in control over steam power gave rise to a steam powered railroad system. This marked the first time in history that people and goods could move across land faster than horse-drawn transportation. This resulted in a crisis of control because the system, as a whole, was not capable of handling the effects brought about by increased transportation speeds; manufacturers struggled to keep up with the inward flow of raw materials, the distribution network could not accurately track the increasing volume of products, and society could not absorb the goods as fast as

producers made them.¹ As established earlier, an increase in control over steam power resulting in increased transportation speed necessitates an increase of control over the rest of the system. The most prominent innovations in control were communication technologies such as the telegraph and standardized railroad signals and innovations in bureaucracy, which led to centralized control and vertically integrated firms.

Thus, the paradox between society and waste can be understood as used in this analysis. Society will always produce waste because processing matter into other forms of matter will always create some form of waste (heat waste, gas waste, solid matter waste). Also, society must control waste to protect the integrity of the system's ability to process matter, because only by continually processing matter does the system maintain itself counter to entropy.

However, notwithstanding society's ability to control the flow of material in and around the system, society lacks adequate control over the waste elimination portion of the system. For an example, one need only to look at the polluted state of our nation's rivers and lakes, or the number of reported illnesses that are linked to environmental pollution. In addition, society's inability to prevent further damage to the ecosystem, let alone reverse the damage, provides evidence to the fact that waste elimination controls are not at the level of control evident in the areas of material extraction, processing, storage, transportation, and consumption.

If Beniger is right and society is a processing system comprised of interconnected parts that are highly reflexive in response to advances in control over its components, then control over waste elimination should have advanced at a pace similar to the rest of

¹Beniger uses the phrase, "crisis of control" to label situations in which the coordination of the flow of energy within a system is compromised to the point of being detrimental to the well-being of the system.

the system's parts. This, however, has not been the case. One must question, therefore: why have waste controls failed to advance at a rate required to control the advances of the other system parts?

Beniger's (1986) analysis not only suggests the question, but it also suggests an answer. He defines control as "purposive influence toward a predetermined goal" (p. 7) and claims that *information processing* and *reciprocal communication* are integral to the task of establishing control.² It stands to reason, therefore, that if control failed to develop in the area of waste elimination then it might be due, at least in part, to a lack of information processing and reciprocal communication in that area.

To be clear about the meaning of the hypothesis, information processing and reciprocal communication (herein jointly referred to as enablers of control) are assumed to be integral components of control, that is, control is not possible without them. As such, the hypothesis is suggesting that waste control has failed to develop because of the non-existence of the enablers of control with respect to the effect of waste on the environment. Stated otherwise, society has lacked the metrics to completely understand the effects of human activity on the environment. For example, chlorofluorocarbons (CFCs) were used in industrial processes long before its damaging effect on earth's ozone was known. In comparison, relative control over economic markets happens quickly and with reasonably predictable results. Society is able to control economic markets because we are receptive to market feedback, meaning society recognizes market information. In addition, society can interpret that feedback into meaningful data that allows us to affect future market conditions through the feedback process. As will be shown in the next

²Information processing is defined as the continual comparison of current states to future states (Beniger, 1980, p. 8). Reciprocal communication is a two-way interaction between or a feedback loop between controller and controlled. See chapter two for a more thorough treatment of these terms.

chapter, this aforementioned control is explained by Beniger's theory of control.

When control over waste does occur, it seems to occur the same way as control over economic markets, whereby society becomes receptive to environmental feedback and learns how human activity affects that feedback. Accordingly, this thesis does not assert that people blatantly and knowingly damage the environment. Instead, it argues that the reason waste control has failed to develop is because the enablers of control have been non-existent, or have been hindered by noise in the communication process, such as interpretation and time delays (Latour, 2005).^{3,4}

To address the question of why this is the case, this thesis will investigate the development of control over wastewater elimination from the mid 1800s to the early 1900s and the development of control over sulfur dioxide production from the early 1800s to the 1960s. Accordingly, it postulates that the failure of waste controls to keep pace with system's parts is related to a *lack* of information processing and reciprocal communication related to problems of waste.

To address these issues the paper will proceed as follows. First, the second chapter of this thesis will summarize control theory, conceptualize the problem and define the terms and variables in the context of the supporting theory. Second, the third and fourth chapters are case studies that focus on the development of waste control technologies for wastewater and sulfur dioxide. The concluding section of this thesis will restate the main findings of this study and its implications, suggest some necessary

³The work done by Latour (2005) is broad and complex and is not applied in its entirety here. This paper is specifically referencing Latour's idea of controversies within the nature of actions, the nature of objects, and the nature of facts. (Latour, 2005, p. 21-22).

⁴Society's inability to develop environmental metrics of human activity is not surprising. When compared to economic markets, the earth is slow to generate feedback information related to human activity.

conditions to promote a faster rate of innovation in waste control, raise some of the questions left unanswered, address the limitations of this study, and suggest areas of additional research.

Chapter 2 – The Theory

Although there is no shortage of literature on the problem of waste and pollution, the application of Beniger's (1986) theory of control to waste and pollution is unique. For this reason the first section of this chapter will provide a thorough overview of Beniger's theory of control and define key terms that will be operationalized later in the chapter. And to maintain a high-degree of fidelity between this study and its primary source text, the majority of key terms and concepts will be conceptualized and operationalized in accordance to the work done by James Beniger (1986) in his book, *The Control Revolution: The Technological and Economic Origins of the Information Society*. This chapter will also build a connection between Beniger's theory of control and the problem of waste control. This theoretical connection will suggest ways to relate waste control problems to the more general societal problem of control. The concluding section will operationalize Beniger's terms, and relate them to the problem at hand. This conceptual framework will provide the basis for the analysis and the organization of this thesis.

Beniger's Theory

According to Beniger's (1986) theory of control, all open living systems must continually process energy in order to maintain themselves against the prospects of entropy.^{5,6} According to the theory, individual system processes must make adjustment

⁵A system is a set of elements that must be related and interacting. A relationship between the elements is necessary but not sufficient as the elements must also be dependent on each other. The need for the elements to be independent is noted in Beniger's observation of the dialectic and evolutionary nature of systems. In addition, there are three types of systems: concrete system, which is a collection of energy and information organized into related and interdependent subsystems within a physically defined area; abstracted system, which is a limited observation of relationships within a system that is selected by an observer; and a conceptual system, which is a collection of words, numbers and symbols (Swanson and Miller, 1989).

to account for changes in the flow of energy (increased processing speed, redirection of material flows, bottle necks).⁷ This theory of control provides an analytical framework for examining the emergent and individual behavior of a system's processes adjusting to variations of energy flowing through itself.⁸ Thus, it may shed light on the answer to the research question addressed in this thesis: *why have waste elimination controls failed to advance at a rate required to control the advances of the rest of the social system.*

There are numerous theories that seek to account for technological development.⁹ Some of the more well known theories include technological determinism (Winner, 1983), social construction (Bijker, Hughes, & Pinch, 1987), evolutionary theory (Basalla, 1988), and actor network theory (Latour, 1987; 2005).¹⁰ All of these theories have unique characteristics that allow them to answer specific questions. That is to say, these theories are analogous to tools, inasmuch as they are designed to answer or address specific questions and problems. As Alex Roland (1992) asserts, different technology development theories "emphasize different aspects of the problem and highlight different

⁶ All matter and material are made up of energy, with the different forms of matter and material representing different physical forms of energy. As such, energy, matter, and material will be used interchangeably depending on the context of usage.

⁷ Individual system processes refer to the parts of the processing system. For example, a person's individual organs are parts of the processing system because they facilitate the flow energy throughout the body. In society, raw material extraction, manufacturing, and transportation networks are individual parts of the society's processing system.

⁸ Beniger's theory of control seems to have much in common with living systems theory and the work of James Grier Miller (1978). However, living systems theory is concerned with the structure of the system and Beniger's approach is much more akin to cybernetics, which is more focused on how the structures operate.

⁹ The switch in focus to technological development is because of Beniger's belief that the degree of society's control over the processing of physical material is directly related to our ability to process information (this concept with elaborated on later in the chapter). Since information processing is almost exclusively done by mechanical controls, the different ways technology is developed and integrated into society must be addressed.

¹⁰ Technology determinism examines the factors that shape technological development, but it doesn't consider the consequences of technological change. Social constructivism takes into account the different social groups that come together to form consensus how a particular should be constructed. Actor network theory examines power dynamics and motives for choices between alternative realities and considers technology a privileged actor in the network of power relationships. Evolutionary theory encompasses the previous three theories and traces the development of a technology over time.

features” (p. 93). He lists, for example, several variables that are addressed differently by each theory. These include external factors such as perceived need, resources, national and regional styles, ideology and philosophy, politics, economics, and science; internal variables such as entrepreneurs and translators, inertia and momentum, institutions, standardization, and secrecy; as well as motivations for technological change such as demand pull and technology push.

Beniger’s theory of control is no different from other theories insofar as it focuses on some aspects of the research question, and not others. Nonetheless it provides a unique approach to understanding the development of waste control technologies. As such, it does not attempt to provide a complete answer to the research question, only a piece of the puzzle. In particular, using Beniger’s theory of control, we can gain insights about how the general laws of physics—in conjunction with thermodynamics and cybernetics—constrain, shape, and necessitate technological development. The laws of physics do not determine technological design; rather they constrain it (Bauchau, 2006, p. 35). In particular, Beniger’s theory of control is an attempt to explain why technology development occurs.¹¹ What is left out, and what Winner, Hughes, Bassala, and Latour and others seek to explain are the forces that actually determine the structure of technology—that is to say, how technological change occurs.

The statement that all living systems are material processors is derived from the second law of thermodynamics and its concept of entropy. In thermodynamics, entropy is the tendency for all matter and energy to lose its ability to work, and then evolve toward chaos—the inevitable and steady deterioration of a system. A system can only

¹¹The development of Beniger’s theory of control was his attempt to develop a unifying set of laws that would explain the approximately 70 societal transformations identified by scholars between the years 1950 and 1984.

counter entropy by continually introducing new energy into the system. For example, burning a lump of coal in a closed system will increase entropy and eventually result in heat death, the point when all energy has been extracted.¹² However, if it is an open system and additional energy (e.g. coal) is added, entropy will be countered and heat death will be avoided. Armed with this understanding of thermodynamics, Beniger concluded that the purpose of all living systems is to process energy, which, in turn, makes all living systems material processors.¹³

While the purpose of living systems is to process energy, as defined by the second law of thermodynamics, the act of processing material is facilitated by the organization of a system's parts.¹⁴ The purpose of organization is evident when comparing living systems to non-living systems. In fact, purposeful organization is one of the defining distinctions between animate and inanimate objects (Beniger, 1986). Animate objects are organized for the explicit purpose of sustaining life, whereas inanimate objects lack purposeful organization. For example, people take in energy (oxygen, food) to be processed by the lungs and digestive system. In turn, the circulatory system transports the energy to the rest of system to maintain life-sustaining functions. And while

¹²A closed system is a system that is unable to take in energy from an eternal source.

¹³Complexity theory can also be used to study the evolution of complex systems. Complexity theory takes into consideration complex adaptive systems, networks of agents that are reflexive in response to other agents, and adaptive learning through feedback loops. The theory also argues that change occurs when a catalyst enters a system operating at the edge of chaos, which is conceptually similar to Beniger's crisis of control. For more on complexity theory see the work of John Holland (1996), Mitchell Waldrop (1992), Stuart Kauffman (1996), and Robert Axelrod & Michael Cohen (1999).

¹⁴A system's organization may be internal to itself, or external. Internal organization facilitates the flow of material within the system. And because a system is itself a unit of energy nested within a larger encompassing system, external organization helps facilitate the flow of the smaller system within the encompassing system.

inanimate objects, such as crystals, are highly organized into complex structures, the order found in the structure of a crystal is without purpose.¹⁵

Society operates the same as a living system.¹⁶ To Beniger, purposive organization in society to counter entropy manifests itself in the economy. The economy's major sectors—primary (extractive), secondary (manufacturing), tertiary (service), quaternary (banking, insurance) and quinary (Medicine, Law, Education) (Clark, 1940; Hatt and Foote, 1953)—serve as the integral components that control the continual processing of material.

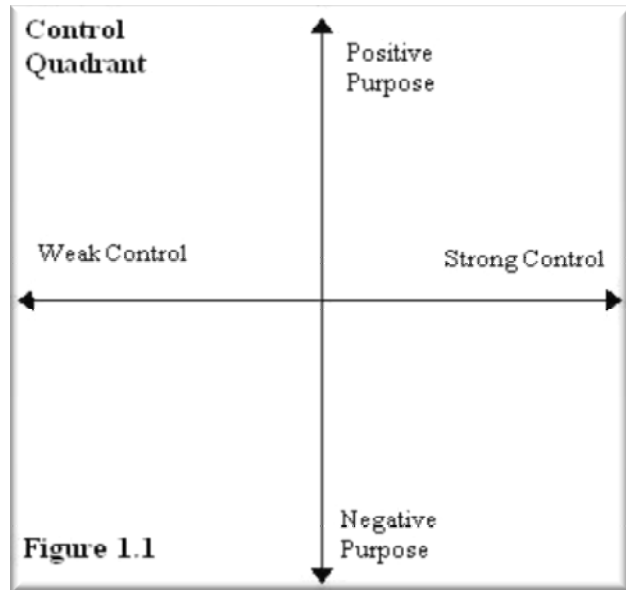
The purpose of organization is to *control* the flow of energy. But before we can show the purpose of organization to be control, we must define control. The meaning of the word control has changed over time. However, historical and contemporary definitions share three basic ideas. First, control is viewed as an invention or technique that affects social, economic, or psychological existence. Second, control is used in the context of the formation and regulation of systems that are used to facilitate the flow of energy. Third, artifacts of control behave in a mechanical fashion that allows the artifact to be absorbed into an existing structure through an exchange of information (Levin, 2000).

For the purpose of this thesis, we use Beniger's definition, which characterizes control as *purposive influence toward a predetermined goal*. This definition not only provides a general definition that can encompass various systems of control (mechanical

¹⁵Beniger was referencing the work of John von Neumann and Colin Pittendrigh.

¹⁶The application of concepts related to living systems to social systems is not original to Beniger. Urban sociology, developed at the University of Chicago during World War I, tried to apply ecological concepts to social organization (Tarr, p xxii, 1998). Abel Wolman, a sanitary engineer, wrote an essay in 1968 titled, "The Metabolism of Cities," in which he compared the flow of material in and around cities to the metabolic cycles of living systems. In 1972 Ronald Johnston argued that cities are open systems similar to ecosystems (Tarr, 1998).

systems, cultural systems), but it also embraces the three shared characteristics of control's definition that are mentioned above. Beniger's definition also builds on the theory of cybernetics—the science of control and communication in the animal and machine. In so doing, it highlights two key aspects of control: "*influence* of



one agent over another, meaning that the former causes changes in the behavior of the latter; and *purpose*, in the sense that influence is directed toward some prior goal of the controlling agent" (p. 7).

Control often carries negative connotations, where control means “insidious, inhuman, or uncaring ultra-rational forces identified with machines” (Levin, 2000, p. 30). However, according to Beniger, the notion of control encompasses the entire spectrum of power, not just the absolute sense of it. Control exists along a continuum of power from weak to strong.¹⁷ Accordingly, control can be said to exist within what will be called a “control quadrant.”

As depicted in the Figure 1.1, the Y-axis defines the positive or negative purpose of control (i.e. detrimental to the system's well-being or enhancing the system's well-being) whereas the X-axis defines the type of control as weak or strong (See Figure 1.1).

¹⁷A continuum of power is used to describe the degree of forced compliance exerted by the control mechanism. Weak control means that the control mechanism is not able to force compliance through mechanical or some otherwise unavoidable mechanism of control, with the opposite being true for strong control.

For example, speed limit signs are designed to influence motorists' driving speeds. Yet, not every driver is influenced by the signs, indicating a form of weak control. Strong control would be exerted when a control mechanism forces compliance, such as automatic speed limiters that regulate driving speeds. The positive or negative purpose of control is a subjective quality that can be operationalized by the context of the situation. Once operationalized, the control measure reflects the values within a particular system of control. The notion of control quadrant provides an important basis for analyzing waste control systems in terms of their degree of forced compliance and the cultural basis for the purpose of the control. Hence, a control system might be Positive and Absolute, Negative and Absolute, Positive and Weak, and Negative and Weak.

Regardless of its position in the control quadrant, a control system can only be established when there are two other components present, which link the controller and the controlled. These include *information processing* and *reciprocal communication* (Beniger, 1986; Weiner, 1948).

Reciprocal communication, the first component of control, can be defined as *a two-way interaction between controller and controlled*. Based on the definition of reciprocal communication (also known as feedback), a two-way interaction between controller and controlled enables the influence from the controller to be communicated to the controlled, and allows the controlled to communicate the effects of the influence back to the controller. As Weiner has said, "When I control the actions of another person, I communicate a message to him.... Furthermore if my control is to be effective, I must take cognizance of any messages from him which may indicate that the order is understood and has been obeyed" (Wiener, 1954, p 16.) This linkage between controller

and controlled is important for the establishment of control because it provides the informational inputs for information processing.

Information processing, the second component of control, can be defined as the “*continual comparison of current states to future states*” (Beniger, 1986 p. 8). As such, information processing allows the controller to gauge the effect of its influence over the controlled with respect to the goal-oriented purpose of the controlling mechanism. So together, the two information activities of reciprocal communication and information processing enable a system of control to be constructed.

To fully appreciate the role of information processing and reciprocal communication in establishing control systems, consider the terms communication and information. Broadly defined, communication can be defined as *the exchange of information*. Communication can occur between people, mechanical devices, people and mechanical devices, people and environments, mechanical devices and environments, and environments. Likewise, information, when viewed in cybernetic terms, can be characterized as *something that reduces uncertainty, restricts choice, or controls something else* (Brate, 2002). Viewed in this fashion, information can be said, as Norbert Wiener has done, to "encompass human languages, machine code, signals in a phone line, body language, and atoms in the air" (Brate, 2002, p. 13). Defined as such, we might think of communication as the exchange of information between entities aimed at establishing control.

A thermostat controlling the temperature of a room is an example of control and its components. The thermostat uses a furnace to influence the temperature of a room with the purpose of reaching a predetermined temperature; the room communicates

feedback back to the thermostat in the form of its room temperature, whereby the thermostat can determine the effect of its influence. "Control, in other words, is nothing but the sending of messages which effectively change the behavior of the recipient" (Wiener, 1950, p. 8).

A more complex control system is evident in the communication structure of a business. Joanne Yates writes,

Flows of downward communication from all levels of management conveyed information, procedures, rules, and instruction to control and coordinate processes and individuals at lower levels. Second, upward flows of communication drew data and analyses up the hierarchy to serve as the basis for managerial control of finances, facilities, materials, and processes. (1989, p. xvii)

Yates' example shows the importance of reciprocal communication in a social setting. Without downward communication employees would not know what action to take, and without upward communication managers would not know the effect of their strategies.

These two examples highlight a distinction between Beniger's theory of control and the concept of control in cybernetics, as laid out by Norbert Wiener. Beniger believes that cybernetics puts too much emphasis on behavior and feedback, and does not account for higher-level programming or maintenance of control. For example, feedback improves the "precision of goal seeking," but it "does not determine it" (Mayr, 1976, p. 391; as cited in Beniger p. 66). A thermostat does not set the temperature or maintain its functionality; it relies on higher-level programming and maintenance from an outside source, such as people or a higher level of controlling software. In a similar fashion,

businesses rely on market feedback to maintain control over their business operations, but managers ultimately must decide how to use that information to direct future goals.¹⁸

It is important to note in this regard that prior to an employee following company procedures, or a thermostat controlling the room temperature, control must exist in a physical form. The physical manifestation of control occurs through programming so that the purpose and influence of control “and the procedures for processing additional information toward that [goal],” (Beniger, p. 40) are physically encoded into a mechanism of control. According to Beniger, there are four different kinds of programming: genetic programming, cultural programming, organizational programming, and mechanical programming. Each of the four kinds of programming can explain a set of behaviors. For example, most animals breathe oxygen because of genetic programming; people behave a specific way in public because of cultural programming; employees wear uniforms because of organizational programming; and mechanical programming controls the actions of anything within its range of influence.¹⁹

Programming, as the physical manifestation of control, continually evolves to maintain control over the flow of energy within a system (Beniger, 1986). This continual evolution in control occurs because the internal workings of a system are interconnected.

¹⁸Beniger may be accused of being a reductionist for his attempt to build a general theory of life around thermodynamics and cybernetics. Indeed he even expresses his desire for a unifying theory and calls the attacks on reductionism “more doctrinaire than practical” (p. 104). Yet, Beniger never admits to being a reductionist, nor does he deny being one. However, Beniger’s treatment of technological and social evolution leaves room emergence and complexity. In that regard, he appears more in-line with sociocybernetics, which was just beginning to emerge as field in the 1970s. Sociocybernetics focused on applying cybernetics to the social sciences. As such, sociocybernetics was faced with the issue of accounting for complexity and nonlinear growth in complex adaptive systems (Geyer & van der Zouwen, 2001). Beniger, not being a sociocybernetist, confronts the problem of accounting for complexity and teleology in cybernetics by arguing for his use of teleonomy (see Pittendrigh, 1958; Huxley, 1960; & Mayr, 1961) –the belief that purpose is derived from the operation of a program.

¹⁹The term program, when used as a noun, represents the broadest example of a control technology. The four areas of programming (genetic, cultural, organizational, and mechanical) denote the next layer of control specificity, with each area of programming being subject to subsequent refinements of definition.

As a result, advances of control in one part of the system require advances of control in other parts of the system. If the system and its individual processing parts fail to evolve and maintain the flow of energy the system will enter into a crisis of control.²⁰

Beniger (1986) believes that this process of continual evolution creates a “dynamic tension between crisis and control,” (p. 220) insofar as each success at control generates a need for additional control. As a result of this dialectical relationship between crisis and control, the social processing system has evolved to control the “extraction and processing of matter, its internal distribution and storage, continuous conversion into energy, and elimination as by-product wastes” (Beniger, p. 37).²¹

While Beniger noticed the dialectic nature of continually maintaining control, Rosalind Williams (1990) noticed the dialectic nature between society’s construction of control systems and the destruction of the environment. In her essay, “Nature out of control: cultural origins and environmental implications of large technological systems,” she examines how “the construction of large-scale technological systems to circulate goods, ideas, capital, and people has promoted the degradation of the visible landscape” (p. 41). Williams’ essay provides several examples of how the social processing system

²⁰There are limits to the analogies between evolution of engineered systems and biological evolution. For example, technological evolution is not random, and technology lacks a “gene” in the biological sense, thereby limiting the ability to track long term variations of change that are visually imperceptible (Ziman, 2000). The difference between evolution, being a natural and random process, and technological evolution, which is not random, is reconciled within Beniger’s theory of control. The reconciliation occurs because of the argument made earlier in the paper that general laws of physics guide the development of technology, but does not determine it. This allows room for conscience decision making by people and other external forces (e.g. cultural style, institutions).

²¹The boundaries of a program’s influence of control are not static, but fluid. Simply because a program is a mechanical control device, it does not imply that it can only control other mechanical devices, it may cross the boundaries of any of the other 3 programming areas. In addition, the boundaries of the program’s influence of control can change. The change may come from social forces, new mechanical technologies, etc. The same is true for all four types of programming.

has been intentionally designed to facilitate the flow of energy, while unintentionally leading to the degradation of the visible environment.²²

To begin, Williams (1990) states that, “circulation is a key contribution of the enlightenment [period] in shaping modern patterns of technological development” (p. 44). During the enlightenment period, philosophers thought the progress of society was dependent on the development of circulation systems (Williams). Circulation was linked to social progress because, at the time, people’s social status was tied to their physical location. So a person who lacked mobility remained fixed in the social hierarchy. In addition, enlightenment philosophers believed that “physical mobility was closely related to social and intellectual mobility” (Williams, p. 55). Thus, starting with the enlightenment period and extending until the start of capitalism, the purpose of circulation systems –which can also be known as networks, connective systems, pathways, or anything that enables the flow of energy between two locations– was to enable the spread of knowledge and ideas.

With the advent of capitalism, social progress was no longer associated with the circulation of ideas and knowledge. Instead, capitalism gave rise to the belief that economic growth lead to social progress. Accordingly, profit, which is an indicator of economic growth, is dependent on the circulation of money.²³ And profit is not produced by manufacturing goods, “but from the mobility of money” (Williams, p. 46). Thus, systems of circulation were no longer sought to increase the flow of ideas, but to facilitate

²²At no point in Williams’ essay does she address the issue of technical systems contributing to the development of waste or pollution.

²³Money is mobile when it is not tied up in physical goods, which remains an assumption of classical economics. As result of capitalists’ desire to maintain the mobility of money, their objective was to decrease the amount of time between when money is invested into a physical good (raw inputs, machine capital, human capital) and sale of the final product.

the mobility of money. Accordingly, technological developments that increased the flow of money were valued by capitalists, which were to be had even at the expense of the environment.

Williams (1990) argues that control over space (i.e. the distance between two physical locations) is necessary to create connective systems. And logically, she argues, control over space leads to a devaluation of place in terms of politics, economics, and intellect. The devaluation occurs because a disconnected place is unable to contribute resources to political, economic, and intellectual systems. As such, only places that were connected were considered to have social value.²⁴ Society's preference for connective systems is evident by the fact that it is the dominant organizing feature in urban and rural settings (Williams). Streets, highways, power lines, and telephone lines are all examples of connective systems that help circulate energy.²⁵

While the development of connective systems does not necessarily lead to the development of waste, it enables increased energy flows and processing speeds, which, as argued earlier in this thesis, leads to the development of more waste. In addition, a place's value is derived from its being a part of a connective system. As such, any waste developed at a particular location was deemed inconsequential, as long as the waste did not interfere with the flow of energy.

²⁴Aesthetic value is not considered because it has no value to political, economic, and intellectual systems. If ascetics play a role in the value of a place, in the case of tourism for instance, then that means people can get to that place, which means the place is connected.

²⁵Williams states that nature can be controlled through technological systems and individual technologies. She focuses on the role of the system in her analysis and distinguishes between two kinds of systems, manufacturing systems and connective systems.²⁵ Though manufacturing systems and connective systems are seen as being different, the former processing energy and the later enabling the flow of energy, she makes the same observation as Beniger and notes that the two systems are dependent on each other. The manufacturing system is dependent on a system of connections so that its processed energy can be released into the larger social system and consumed, and the connective system needs energy to transport in order to maintain its necessity as a system.

The practice of ignoring the cost of pollution in the manufacturing of goods represents an external diseconomy. As a whole, pollution represents an external diseconomy. And today, finding ways of internalizing the cost of pollution to producers is a common approach to solving the problem of diseconomies. To explain what diseconomies are and why they exist three paragraphs of text from an article by Paul H. Gerhardt (1968), whom does an excellent job explaining the subject of diseconomies in relation to environmental pollution:

The economist sees air pollution as a classic case of an external diseconomy. External diseconomies arise whenever market forces alone are insufficient to make an individual bear the full costs including the social costs that result from his actions. If these costs can somehow be internalized so that the economic unit generating pollution is required to pay for its elimination, then the diseconomy is removed.

In a profit-motivated economy profits are maximized to the extent that the cost of waste disposal is minimized. Profits are also maximized to the extent that waste is turned into valuable by-products or recovered products. When the value of such products exceeds the costs of producing them, waste reduction, like the practice of honesty, is its own reward. When the costs of waste reduction and disposal are not offset, the costs of disposal are borne by others than the producer of the wastes. The costs are clean-up and disposal costs. Or they are personal, material, and esthetic damages that are suffered in tolerating polluted air, putrid water, and a trash-littered landscape.

The producers of pollution are generally unaware of the total effects of the pollution they produce. No one producer has an incentive to eliminate his pollution entirely; his incentive, commonly, is limited only to the elimination of that part which adversely affects his own operation. The arguments against going farther are that it will cost too much, that prices will have to be increased, that consumers will not buy it, and that there is no proof that air pollution is damaging anything anyway, so why pick on me. (p. 359-360)

The quote from Gerhardt implicitly embodies most of the debate about pollution. His quote also fits into the framework of this paper. As we can infer from the above passage, diseconomies are problems of reciprocal communication, whereby a producer of pollution is unaware of its cost because the costs are distributed across members of society.²⁶ Diseconomies are also problems of information processing, where attempts to control pollution are challenged by claims of validity in establishing cause and effect between anthropogenic activities of society and the degradation of the environment.

Today, economic pricing is one of the primary control mechanisms used to control waste, which is a part of the organizational level of control. Economic pricing forces the market to realize the cost of environmental pollution, thus correcting, or at least diminishing, the market failure that allowed environmental pollution to be treated as an externality. An example of economic price signaling as a program of control is the Clean Air Act Amendments of 1990, whereby a cap and trade system was put in place for

²⁶Depending on the type of pollutant the cost of the pollution may not be evenly distributed across all members of society. For example, farmers that spray their crops with pesticides increase their crop yield, which translates into lower food costs for consumers through forces of supply and demand. However, the local residents of the farming community bear any environmental costs associated with the spraying (e.g. water pollution, increased health risks).

emissions that can cause acid rain. A similar market approach is used for carbon dioxide in the Kyoto Protocol.

Despite centuries of attempts to control and eliminate waste, it is an inevitable part of the energy life cycle. Waste's inclusion in the flow cycle of energy its elimination is subject to control via *information processing*, and *reciprocal communication*.

Summarizing the connection between the four key terms: *waste* is a result of the continual flow and conversion of energy; the flow and conversion of energy, including the flow of waste, is dictated by the system's organization, the purpose of which is *control*; finally, control is dependent on *information processing* and *reciprocal communication*.

The succinct explanation of the relation between waste, control, information processing, and reciprocal communication obscures the complexity of the process by which energy flows through society. For example, society consists of "relatively autonomous components - individuals, families, groups and organizations - that can act for different and even cross-purposes" (Beniger, 1986, p. 38). And because energy processing depends on the exchanges of these specialized and differentiated individual components of society, "the need for their coordination and control means that information processing and communication will account for a relatively greater proportion of matter and energy flows" (Beniger, p. 38) as the system grows in complexity. This phenomenon occurs because information provides an open system the means to control and influence energy conversion for the purpose of preventing heat death.

Yet information is epiphenomenal to material processing. That is to say, information is derived from the organization of matter and energy. Because information is epiphenomenal to material processing, information related activities increase as material processing increases; the same is true for waste. The more waste society creates the greater the need for information to establish and maintain control over the waste elimination processes.

Waste

Now that a theory of control has been developed, and the relationship between waste, control, information processing, and reciprocal communication within the context of open systems has been established, we need to look more closely at the subject of waste. This section examines the role of waste in life systems as characterized in Beniger's theory of control as well as contemporary definitions of waste.

Waste can be studied from a variety of disciplines –law, political history, health, environmentalism, ecology, economics, urban history, physics, etc. For the purpose of this paper, waste will be conceptualized from the perspective of thermodynamics, ecology, and culture.

Thermodynamics

The first law of thermodynamics states that energy can neither be created nor destroyed, only converted into other forms of energy. The second law of thermodynamics states that converting energy into other forms will always produce some less useful form of energy; this is known as entropy. As such, *waste is produced when the energy contained within a system reaches the point of entropy within the consuming system*. For example, cows obtain energy from the ingestion of plants and minerals.

When all of the energy from the food has been extracted (i.e. reaches the point of entropy), the resulting waste is eliminated from the cow's system in the form of excrement, commonly referred to as manure.²⁷ Also, as stated earlier in the paper, thermodynamics explains what all living systems are designed to do: "control the extraction and processing of matter, its internal distribution and storage, continuous conversion into energy, and elimination as by-product wastes" (Beniger, 1986, p. 37).

Ecology

A basic definition of an ecosystem is, "a functional group of interdependent parts including organisms and physical features" (Liu, 2005, p. 2). Ecosystems may vary in size and form, but in terms of earth's ecosystem there are three main structural parts: atmosphere (air), hydrosphere (water), and lithosphere (earth). The ecosystem is, moreover, made up of two main components: biotic (living objects) and abiotic (non-living objects). The biotic category includes: herbivores, carnivores, omnivores, and detritus consumers. The abiotic category includes chemical compounds, both organic and inorganic (Liu, 2005).

Essentially, an ecosystem is an organizational system that facilitates the flow of energy. As such, ecology and its concept of ecosystems defines the three domains in which waste can exist –atmosphere, hydrosphere, and lithosphere– as well as the components of the ecosystem that waste can effect –biotic and abiotic.

Cultural Perspectives

²⁷ Emphasis needs to be placed on the understanding that waste is produced when energy reaches the point of entropy *within the consuming system*. While the cow may not be able to extract any more energy out of the food, thus necessitating the need for its elimination, this does not mean that manure has no value in terms of energy to another system. For example, manure is often used as a fertilizer to help plants grow.

Waste is commonly understood to be any substance or article that requires to be disposed of.²⁸ Absent from this definition of waste is the term pollution, which raises the question, is all waste pollution? Conversely, is all pollution waste? Clearly a distinction exists between the two. According to this thesis, waste is the refuse of a system. Matter becomes refuse when it reaches entropy within the consuming system.²⁹ When matter is discarded as waste, should it be automatically classify as pollution? No. For example, household trash is a form of waste. Yet, if enough household trash is concentrated into one spot it can become pollution. So at what point does waste become pollution? Pollution is commonly referred to *as any matter that degrades a system's ability to sustain life and/or other living systems*. As such, all pollution is waste because of its inability to provide the host system with usable energy. Even the most seemingly benign pollution, such as light and noise pollution, degrade a system's ability to sustain life – light pollution can disrupt the growth cycles in plants, and sufficient noise pollution can cause physical and mental damage to living systems. Accordingly, not all waste is pollution, but all pollution is waste. Thus, this thesis will only address the development of waste control technologies when the waste is deemed a pollutant and waste controls try to prevent waste from becoming a pollutant.

Methodology

The prominent theories underlining Beniger's analysis of control is cybernetics and thermodynamics. As Beniger (1986) himself notes, his analysis of the control revolution is "motivated not by any organismic model but by the more modest conviction

²⁸Waste can occur as a result of natural forces, such as a sulfur gases from a volcano or carbon monoxide from respiration.

²⁹Matter does not have to reach the maximum state of entropy to become waste. Matter only has to reach a degree of entropy that would require the system to expend more energy than in it would receive in the extraction process to be deemed waste.

that all concrete control systems—both individual and collective—must overcome the same fundamental problems if they are to maintain themselves counter to entropy” (p. 68). Yet, Beniger is a social scientist as well as a polymath. Not surprisingly, he infuses theories from economics, social science, history, anthropology, etc, to substantiate his claims of causality.

Beniger recognized the applicability of cybernetics to the study of complex social systems, as did many others (Talcott Parsons, 1962; Norbert Wiener, 1952). However, cybernetics has limitations as a theoretical framework in the social sciences. As notable sociocybernetists Felix Geyer and Johannes van der Zouwen (2001) note in their book “Sociocybernetics: complexity, autopoiesis, and observation of social systems”, as social systems grow in complexity, “cybernetic theories become more relevant and fitting, but less testable as they grow more complex themselves” (p. 12). Beniger understood the difficulty of testing his hypothesis using cybernetics alone, which helps explain why he brings in so many other theories. He needed the other theories to help explain what cybernetics could not. Most notably, Beniger had to account for the complexity and adaptive nonlinear growth of social systems. In addition, he had to overcome the teleological biases found in cybernetics. As argued earlier, because Beniger is not a determinist, he supports a teleonomic perspective –that is to say, a perspective that attributes the goal directedness of a process or behavior to the operation of a program (Pittendrigh, 1958; Huxley, 1960; & Mayr, 1961). In contrast, a teleological process owes the goal directedness of the program to the behavior of the system. Thus, teleonomy helps argue the case that a program exists prior to the phenomena it explains (Beniger).

This thesis must address the same problem that Beniger faced in his book—that is, how does one explain cause and effect in complex macro-societal processes such as the development of waste controls? For Beniger, macro-societal processes can be explained by focusing on the four levels of control—genetic, cultural, organizational, and mechanical. He states that macro-societal phenomena are complex because “they are controlled by multiple, multilevel, and densely interconnected programs” (p. 42). So by focusing on the four levels of control, the complexity of the system is at least addressed directly, “rather than through reification of planning and purpose to the aggregate level” (Beniger, p. 42). This thesis follows a similar methodological approach; it examines the effect of information processing and reciprocal communication on the development of waste control within the genetic, cultural, organizational, and mechanical levels of programming. Table 2.0 is the same one used by Beniger to conceptualize the various levels of control and the forms of programming that are nested within each encompassing level of control. The Table also provides measurable dimensions that reflect the controlling technologies influence or response to the three problems of establishing and maintaining control, which are only mentioned in this thesis. Table 2.0 provides the operational guidelines by which a specific program can be classified as being a part of the genetic, cultural, organization, or mechanical level of control. To classify the program we look at its physical or metaphysical form, the type of processor(s) within the program, or the program’s response to the problem of existence, experience, or evolution.³⁰ After

³⁰Beniger (1986, p. 112) identifies three problems to establishing and maintaining control. The first problem is *existence*, that is to say, maintaining the organization to avoid entropy. The second problem is *experience*, which requires the system to continually adapt goal-directed behavior in response to varying inputs to the system. The third problem is evolution, whereby the system must maintain successful control mechanisms while weeding out less successful ones. Since controlling waste is nested within the larger problem of control, the three problems to establishing and maintaining control must be applicable to the development of waste controls.

identifying and classifying a program, we identify the program's relationship to the object it is controlling.³¹ This can be done by identifying the goal-directed purpose of the program.

To explore the hypothesis of this thesis, which states that *waste control has failed to develop because of a lack of information processing and reciprocal communication related to waste, and that information processing and reciprocal communication are subject to noise, such as interpretation by social actors and time delays* (Latour, 2005), we must explore the role of information processing and reciprocal communication with regards to the development of waste controls. The thesis will also test the null hypothesis. The null hypothesis states that the development of control is not a function of information processing and reciprocal communication and that communication process is free of noise. To test this, the thesis will look for instances when the establishment and maintenance of control is not dependent on information processing and reciprocal communication or when communication process is free of noise.

³¹The object may in a physical or metaphysical form.

Table 2.0 Analytic dimensions and empirical properties of the four levels of control, including the type of social possible at each level. (Source, Beniger, 1986, p. 103).					
	Organization of Matter and Energy		Analytic Dimensions of the Resulting Control Systems		
Level of control	Processors	Programming	Existence	Experience	Evolution
<i>Level One: Life</i> Genetically based sociality (many species)	Molecules of DNA	Genetically inherited programming	Replication of programming, protein synthesis	Response, adaption of genetically controlled processes to environment	Organic evolution through natural selection
<i>Level Two: Culture</i> Culture-based social structures; human societies	Vertebrate brains	Learned behavioral programs	Behavior controlled by programming stored in memory	Learned responses adaption to environment through reprogramming	Cultural diffusion, change through purposive innovation, differential adoption
<i>Level three: Bureaucracy</i> Bureaucratically controlled social systems	Formal organizations of individuals	Explicit rules and regulations	Rationalized processing, record keeping, hierarchical, decision, formal control	Organizational response to environment, adaptation through reorganization, procedural changes	Diffusion of rationality with differential adoption as culture, selection pressure on organizations
<i>Level Four: Technology</i> Technobureaucratic information society	Mechanical and electronic information processors	Purposively designed functions and programs	Informational inputs, processing and storage, programmed decision and output	Interaction of processor and environment, adaption through reweighting, reprogramming	Diffusion of processors and programs with differential adoption as culture, government, and market selection

Before setting about to falsify the hypothesis, let us think about some of the assumptions of Beniger's theory of control that have been described thus far. Control is

manifested through programming, and no program is created or enacted without information processing and reciprocal communication. In relation to this thesis, this means that control over waste cannot occur without a program, and programs are never created in the absence of information processing and reciprocal communication. As such, attempting to falsify the hypothesis by looking for an instance where control is developed without the presence of information processing and reciprocal communication seems futile. Accordingly, emphasis will be placed on finding out whether or not noise has an effect on information processing and reciprocal communication.

Conceptual Framework

By drawing and restating the conceptual relationships between controller and controlled we can determine the instances when information processing and reciprocal communication is present. Table 2.1 shows the hierarchy of relationships between environments, systems, programs, and systems of control. Figure 2.2 shows the interaction between a system and the system's environment.³² As figure 2.2 shows, System A sends output to the environment and receives input back from the environment.³³ Accordingly, it can be understood that the “variables describing the actual state $\{S(t)\}$ and output of a system $\{O(t)\}$ are thus dependent on its input $\{I(t)\}$. Or, $S(t), O(t) = f[I(t)]$ ” (van der Zouwen & van Dijkum, 2001, p. 225).

³²Environment does not denote natural environment.

³³Because environments are all encompassing and can contain other systems and program, the feedback does not have to come from the environment per say, but from another system or a program.

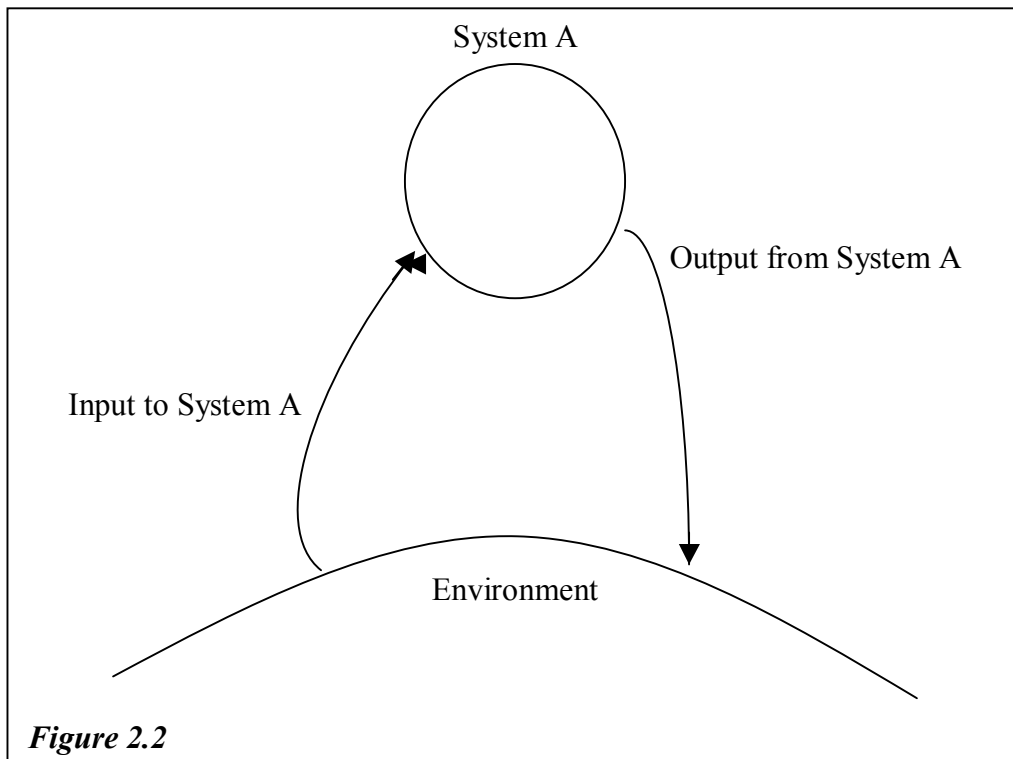
Relational Hierarchy of Environments, Systems, Programs and Control

- **Environment:** the area surrounding the boundary of a system. It also provides the energy input for living systems. Environments may be man-made (e.g. office building, city, cultural environment), natural (e.g. forest, savannah, ocean). The boundary of an environment may change depending on the definition, which means that an environment can consist of both artificial and natural components. Environments may be as large as the entire planet's ecosystem, or as small a pot of soil.
 - **Living System:** A system of related and interdependent elements enclosed within a definable boundary (the boundary may be physical or metaphysical) that sustains itself by continually processing energy. Systems are always located within an environment. It may also be an environment if at least one other system is nested within it. Systems may be as large as the entire planet's ecosystem, or as small as a single cell organism. Systems may be artificial or natural.
 - **Program:** The mechanism by which the flow of energy is maintained within a system. Programs are nested within systems and systems can have many programs. There are four levels of programming: Genetic, Cultural, Organizational, and Mechanical. Within each level of programming are individual programming mechanisms (refer to table 2.0 for a description of programming levels). Programs may also have sub-programs that help maintain the functionality of the larger program. Programs exert control over other programs, systems, or environments for the purpose of controlling the flow energy (energy can represent all physical forms of energy and all metaphysical forms such as ideas, information, knowledge).

The relationship between a system and its environment is complicated when the goal seeking behavior of a system is considered, this behavior is also considered homeostatic (van der Zouwen & van Dijkum, 2001). Noting the ability of systems to maintain their state variables at nearly constant values in the face of constantly changing input variables, van der Zouwen & van Dijkum believe that systems “have desired values

on the state variables $\{S(g)\}$ and output variables $\{O(g)\}$, values which they try to reach and maintain. Accordingly, changes in inputs, which result in undesirable state and output variables, prompts the system to take countermeasures, which is usually by done changing the system's input variables, thereby creating a feedback loop between the input and output of the system (van der Zouwen & van Dijkum). The feedback loop can be expressed as, $I(t) = f[\{S(t) - S(g)\}, \{O(t) - O(g)\}]$ (van der Zouwen & van Dijkum).

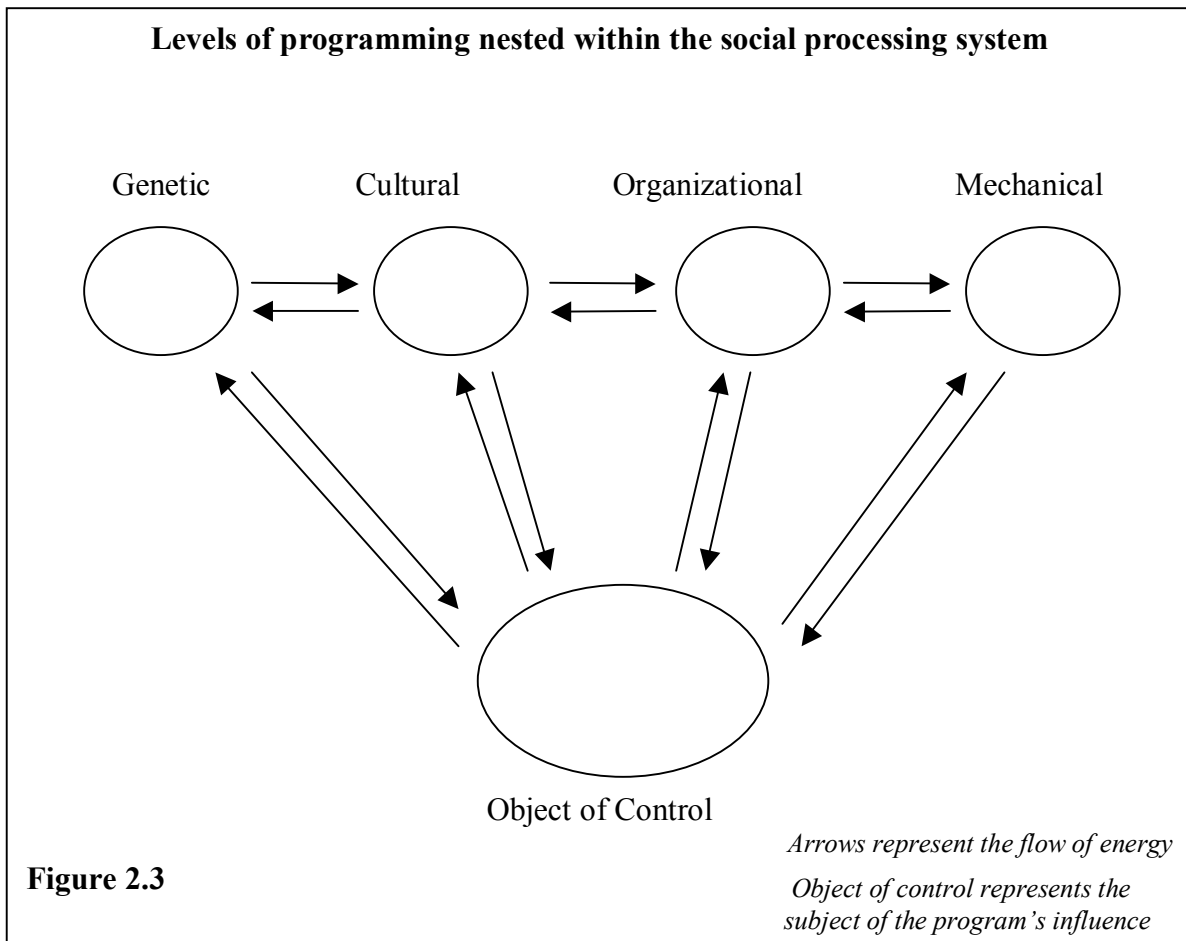
According to Table 2.1, environments contain systems and the subsequent programs of systems. Based on Figure 2.2, we can infer that the inputs coming into a system from the environment are actually coming from another system or program. Furthermore, it is reasonable to assume the outputs from the system, upon entering the environment, may become inputs to any number of other systems within the environment before leaving as input back to the original system. This interconnectedness between system's programs begins to show how complex energy flows can be.



The interconnectedness of systems affects the understanding of reciprocal communication, which was previously defined as a two-way interaction between controller and controlled. It can now be argued that reciprocal communication does not have to be direct two-way interaction between controller and controller, it can also be indirect. Indirect reciprocal communication occurs when the line of communication between controller and controlled is routed through another system or program.

Now that the relationship between systems, programs and control has been established, we can develop a conceptual map that relate more closely to the research question at hand. As noted above, the thesis examines the development of societal control over waste elimination. Accordingly, it looks at specific programs of control as found in the four levels of programming –genetic, cultural, organizational, and mechanical– that have the purpose of controlling the flow of waste. In addition, this thesis looks for evidence that would indicate that the control program was developed in the absence of information processing and reciprocal communication.³⁴ Figure 2.5 shows the web of relationships between the four levels of programming and the generically conceptualized ‘waste’ that needs to be controlled.

³⁴Controlling the flow of waste can mean preventing from waste from occurring, transporting it away from society, or processing it so that it no longer poses an environmental risk to people or to the natural environment.



Methodological Concerns

There is one weakness in this methodology that needs to be mentioned. It stems from the presence of reciprocal communication, or feedback. Reciprocal communication presents a problem because in the social sciences, a cause and effect can only be one-way, that is, an effect cannot influence the cause. Yet, with reciprocal communication, this is exactly the case. As described in this analytical framework, influence from the controller (X) is communicated to the controlled (Y). To complete the feedback loop, Y communicates the effect of X's control back to X, at which point X may change its influence over Y. To overcome this problem of feedback and cause and effect we do not

treat the controller and the controlled as the cause and effect. Instead, the cause is information processing and reciprocal communication, which together are referred to as *enablers of control*, and the effect is the establishment of control. Accordingly, the enablers of control (information processing and reciprocal communication) affect the establishment of control, and the establishment of control does not influence the enablers of control. Thus, cause and effect constitutes a one-way relationship.

Also, as some readers may have realized, there are indeed times when control can be established and maintained without information processing or reciprocal communication. For example, a thermostat may keep the temperature of a room constant without feedback, (i.e. without knowing the temperature of the room) if the rate at which the furnace heats the room and the rate at which the room changes temperature remain constant. For example, if a thermostat heats a room at a rate of 5° per 10 minutes and the room cools down at a rate 5° per 60 minutes, to maintain a room temperature of $\pm 5^{\circ}$ the furnace would have to stay on for 10 minutes of every 70 minute time period. However, this system of control breaks down if there is a variation in the rate at which the room temperature changes because without feedback the thermostat will be unable to account for the varying rate of temperature change.

Control can also be maintained without information processing between controller and controlled. For example, imagine a car manufacturing company and its sales department. The car manufacturing company can build cars without processing any information from its sales department. Of course, this assumes a constant rate of car sales with no deviation in the number of cars sold over the course of time. However, if the company is producing car models X, Y, and Z, and only models X and Y are selling,

then eventually the car sales lots will reject shipments of model Z car, which means the model Z car will have to stay at the factory. If enough Z models accumulate at the factory then the flow of material from the manufacturing plant will be disrupted. Yet, if the car manufacturer had processed the information it received from the sales department it could have adjusted its production numbers to correspond with the number of cars it was selling.

To overcome the theoretical situations when control can be maintained in the absence of information processing and reciprocal communication, the term *dynamic control* is introduced. Dynamic control refers to a situation in which the energy flow in, through, and out of a system can randomly vary and must be controlled for. Since it is realistically impossible, as time goes to infinity, to control for all random variation in even simple systems of control, let alone complex ones, all control systems analyzed in this paper will be assumed to be dynamic control systems. (Beniger addresses the issue of random variation in energy flows when he identifies his three problems to maintaining and establishing control—existence, experience, and evolution.)

Chapter 3 – Controlling Wastewater

This chapter will cover the historical development of sewer systems in America from around the mid 19th to early 20th centuries.³⁵ This time period was chosen because sewer systems continue to pollute many of America’s waterways, and most of this pollution can be traced back to early decisions about sewer design. Accordingly, retracing the informational feedback loops and looking at how systems processed information in regards to sewer systems should yield insights into whether or not society knowingly polluted the environment, or if they lacked the metrics (i.e. information processing and reciprocal communication) to understand the repercussions of their actions.

The first part of this chapter will provide a historical account of the events that led to the development of sewer systems. This part will help contextual the problem, variables, and scope of examination. It will also illustrate the dialectic between increased control over material flow and the subsequent need for more control. The second part of this chapter will define the variables and apply the analytical framework that was described in chapter two. The third part will draw conclusions with respect to this thesis’ hypothesis and research question.

Historical Background

The industrial revolution led to the development of large cities. These cities often developed next to major sources of water—navigable rivers, harbors, and freshwater sources. This choice of location occurred because water is a key input for the

³⁵Because of the of time constraints for the data collection of this chapter, only sewer systems developed in the Eastern part of the United States are looked at. Also, the majority of the data focuses on the development of feedback loops and how information was processed. Accordingly, specific types of systems are not looked at. It is a macro perspective of what was happening at the time.

development of the social processing system. Water provides nourishment for people, it can be used in industrial processes, and it can provide transportation for goods and services. At a basic level, water is a key input from the environment because it enables and assists the flow of energy throughout society.

However, in the early 1800s as cities grew in size and density, the flow of water into the cities was becoming a problem. Before they had running water, most urban dwellers had obtained water from wells located in town squares, rainwater cisterns, or natural springs. Yet, these sources were limited in their ability to provide sufficient quantities of water to sustain the large populations of people that settled around them. To address this problem, municipal and private water systems were constructed to supply running water. In 1802 Philadelphia constructed America's first public water works.³⁶ By 1860 sixteen of the largest cities had public water systems and 598 cities had running water by 1880 (Tarr, 1996, p. 133).

Joel Tarr (1996), a noted urban historian, observed that water demand interacted with water supply. "Chicago water usage, for instance, went from 33 gallons per capita per day in 1856 to 144 in 1882; Cleveland increased from 8 gallons per capita per day in 1857 to 55 in 1872; and Detroit from 55 gallons per capita per day in 1856 to 149 in 1882" (Tarr, p. 133).³⁷ Interestingly, while cities built large systems to increase the inward flow of water, no means of removing the increased amounts of wastewater was constructed at the same time (Tarr, p.133).

³⁶This date varies by source. Some sources claim 1801, others 1802 and 1804. 1802 was selected because it is the most frequently cited.

³⁷Tarr (1996) acknowledges that those numbers include both household water usage and industrial water usage, but he says that those numbers illustrate the overall increase in water consumption.

Prior to the development of sewer systems, wastewater was disposed of in cesspools and privy vaults.³⁸ Historical accounts describe cesspools and privy vaults as holes in the ground lined with brick or stone and often located next to homes or even in basements. The wastewater contained in these holes would leach away into the soil and any solid material left in the hole would either be removed by waste scavengers, farmers or left in the hole and buried when it became full.³⁹ Historians estimate that people in Manhattan were depositing over a million pounds of wastewater and refuse into the ground every day.

However, running water stressed the system of cesspools and privy vaults. As noted earlier, water usage increased substantially after the introduction of running water, and part of this increase was due to the adoption of the water closet (also known as the flush toilet).⁴⁰ Water closets were typically designed to drain directly into the privy vaults and cesspools, which could not handle the increased amounts of wastewater. By 1860 Raufer (1998) stated that wastewater was overflowing the privy vaults and cesspool system of Philadelphia, “soaking the city’s water tables with polluted water, and turning streets and residential areas into soggy seas of fecal matter” (p. 61).

Wastewater was also seen as a health hazard, and not just a nuisance pollution. A prominent belief among health officials was that disease was caused by miasmas produced from decaying matter (anticontagionists).⁴¹ Accordingly, they believed that the

³⁸Tarr (1996) calls the time period between 1800 and 1880 the pre-sewer period, as most sewer systems were not developed until after that time.

³⁹Waste scavengers and farmers would collect the waste and either dispose of it in local waterways, or use it as fertilizer on agricultural fields. Often the scavengers and farmers would be under a contract from the city to remove the waste.

⁴⁰See *Pollution Markets in a Green Town* by Roger Raufer (1998) for a historical account of the water closet’s development.

⁴¹There was small group of scientists who disregarded this theory and believed that disease was from specific contagia that were probably alive. These people were considered contagionists.

fecal matter found in wastewater would lead to epidemics of cholera, typhoid fever, and yellow fever.⁴² Benjamin Lee, the secretary of the State Board of Health of Pennsylvania in 1894, is quoted as saying that, “no water closet should ever be allowed to be constructed until provision has been made for the disposition of its effluent in such a manner that it shall not constitute a nuisance prejudicial to the public health” (as quoted in Tarr, p. 115-116). And indeed, wells that were polluted with wastewater from privy vaults caused several outbreaks of typhoid fever and cholera.

As Tarr (1996) put it, “the adoption of the two new technologies of piped-in water and the water closet, therefore, combined with higher urban densities to cause the breakdown of the privy vault-cesspool system of waste removal and to increase its productivity of both nuisance and of real and perceived health hazards” (Tarr, p. 133). As a result, sewer systems were constructed to address the breakdown of control.

The most common type of sewer system constructed in the late 19th and early 20th centuries were combined sewers.⁴³ This meant that the sewer carried both household and street runoff wastewater, which was to be disposed of in local lakes, rivers, and harbors. The decision to empty the sewers into waterways was because of the theory that running water purified itself.⁴⁴

⁴²In the early 1800s the cause of yellow fever was thought to be from contaminated wells. L. O. Howard, M.D., (1921) stated that even in 1871 there was no mention of any disease being insect borne in standard medical treatises (p. 413). Howard does note that Louis D. Beauprethuy, a French physician, argued that mosquitoes carried yellow fever in 1853, but the mosquitoes acquired the disease after visiting decaying matter, which illustrates Beauprethuy’s belief in the anticontagionist theory.

⁴³Separate sewer systems that carried rainwater and household waste separately were an alternative to the combined system. However, because of the large amounts of horse manure in the streets it was deemed that the street runoff was just as polluted as household wastewater (Tarr, 136). Also, separate systems were more expensive to build, which deterred many cities from investing in them.

⁴⁴Engineers and scientists were unsure as to how far the water had to travel or how fast it had to move for purification to take place (Tarr, p. 121).

It is here that we see the dialectic relationship between crisis and control that Beniger (1986) discusses. Control over running water increased its input into the social processing system. As society processed more water it created more wastewater, thereby overrunning the old control system of privy vaults and cesspools. In turn, society regained control over the elimination of wastewater by creating another control technology, sewer systems.

Applying the Analytical Framework

The Relational Hierarchy of Environments, Systems, Programs, and Control in the Development of Sewer Systems

The environment: For this chapter, the system is the social processing system. Therefore, the environment includes the hydrosphere, the lithosphere, and the atmosphere surrounding the social processing system. Also, the pollution being examined in this chapter specifically affects the hydrosphere, lithosphere, and biotic organisms.⁴⁵

The system: The system is the social processing system, which includes all elements of society—institutions, factories, laws, people, buildings, etc.⁴⁶

The program: Sewer systems are programs that control the elimination of wastewater. Sewer systems are also a part of the mechanical level of programming, which is evident by its mechanical processors and purposively designed function to remove wastewater (See table 2.0).

Control: Sewers are purposively designed to facilitate the removal of wastewater from urban environments.

⁴⁵There is some affect on the abiotic elements, but it is primarily aesthetic and does not degrade the system's ability to maintain itself counter to entropy.

⁴⁶There are smaller environments and systems nested within the supra system and environment. For example, Pittsburgh can be considered a local system of related and interdependent parts nested within a local environment.

Measuring the Variables

Reciprocal Communication: Reciprocal communication will be measured by examining the flow of the sewer's influence (the controller) over the elimination of wastewater (the controlled). Accordingly, the feedback loop will be examined by looking at how influence from the controlled was communicated back to the controller through the four levels of control (genetic, cultural, organizational, and mechanical).

Information Processing: Information processing is difficult to measure directly. As such, a proxy measure will be used. A proxy measure will be determined by examining the literature concerning the effect of sewers on the health of the system. Such literature will include professional journals, institutional reports and memos, scientific reports, and literature reflecting cultural beliefs.

Noise in the Communication Process: Noise will be determined by looking for disputes over information or lack of understanding about the relationship between the health of the system and sewer pollution. Noise will be examined throughout the four levels of programming.

Data

Reciprocal Communication

Sewer systems are designed to eliminate wastewater from urban environments. It is necessary to eliminate this pollution because it degrades the social processing system's ability to process energy—the workforce was subject to outbreaks of cholera and typhoid fever, potable water was unavailable for consumption, and polluted water hindered industrial processes such as textile manufacturing. Unlike modern sewer systems, early sewers lacked the ability to receive direct feedback from the flow of wastewater to

determine the effectiveness of its control. As such, any feedback concerning the sewer's effectiveness would be indirect, that is, from another program or system.

Based on how sewers were developed we can determine two indicators of feedback. First, feedback from the program can be found at the genetic level in the form of outbreaks from cholera and typhoid fever. These outbreaks are then communicated to the cultural and organizational levels of control through instances of disease and sickness, thereby allowing authorities to evaluate the effect of the program's influence over the elimination. Note, the effectiveness of the sewer system can only be measured this way because health officials knew about the link between wastewater pollution and instances of cholera and typhoid fever. The second indicator would be the visible absence or presence of wastewater from city streets and homes. For example, if wastewater is present, then it can be determined that there is a problem with the program; if wastewater is not present then the sewer could be assumed to be properly functioning.

By applying the work by van der Zouwen and van Dijkum (2001) we can further characterize the feedback loop and the relationship between energy input and output. The state of the social processing system $\{S(t)\}$ and its output $\{O(t)\}$ are dependent on its inputs $\{I(t)\}$. As applied to wastewater, we can see that the social processing system was affected by the input of polluted water. Furthermore, the social processing system appears to have a desired state of being $\{S(g)\}$ and desired outputs $\{O(g)\}$, as indicated by the system's decision to eliminate wastewater to affect the current state of the system and its outputs.⁴⁷ Stated otherwise, $I(t) = f[\{S(t) - S(g)\}, \{O(t) - O(g)\}]$.

⁴⁷The term goal does not imply equilibrium. The term is meant to mean desired state. Therefore a desired state of disequilibrium is still a goal.

It can also be argued that society understood this relationship between the system's state, the system's outputs, and environmental inputs. For example, health officials understood that people got sick from the inputs received from the environment. It was also understood that the state of the environment was a function of the social processing system's output. In 1843 the College of Physicians in Philadelphia unanimously voted to adopt a resolution asking the city to take measures that would ensure the protection of the Schuylkill River's water quality. Such measures included buying or using eminent domain to obtain shoreline property to prevent pollution from entering the river (Raufer, 1998). The social processing system understood that people got sick from the inputs received from the environment,

Information Processing

Programs can receive feedback from the controller, but if it fails to act on the received information it will be unable to maintain control over the flow of energy. Based on a review of the bibliographies of several historical accounts of sewer development it can be concluded that information processing about the effect of sewers on the environment was present.

The bibliographies of *The Search for the Ultimate Sink*, (Tarr, 1996); *The Impact of Sanitary Reform upon American Urban Planning, 1840-1890* (Peterson, 1979); *Filtering the City's image: Progressivism, Local Control, and the St. Louis Water Supply, 1890-1906* (Shapiro-Shapin, 1999); *History of Sanitation* (Cosgrove, 1909); *Sewering the Cities* (Cellini, 1977); and *The Cholera Years* (Rosenberg, 1962) contain hundreds of articles, reports, and books from professional journals, scientific reports, census reports, governmental institutions and newspapers from the early 19th century to the first quarter

of the 20th century. The literature is related to the effect of wastewater pollution on the environment and the subsequent effects on the social processing system.⁴⁸

Noise

This analysis suggest the following conclusions: First, sewer systems are a program of control designed to facilitate the removal of wastewater from urban environments. Second, the enablers of control are present within this system of control. Third, the historical events leading up to the development of sewer systems is an example of the dialectical relationship between increased processing speeds the need for additional control as explained by Beniger (1986). Accordingly, everything up to now is in agreement with the theory laid out in the previous chapter. However, the question remains as to whether or not society knowingly polluted the environment or if it lacked the ability to measure the consequence of its actions. Since we can conclude that the enablers of control were present and yet society continued to pollute, we must look at the role of noise within the decision making process.

One possible source of noise could have been that medical scientists did not know what made people sick. In the 1850s a common belief was that decaying matter put off harmful gases that, when inhaled, would cause people to get sick. This was known as the filth or pythogenic theory (Tarr, 1996, p. 137). Belief in this theory caused people to assume that sewage and wastewater had to be disposed of as quickly as possible, which led them to dispose of it in open sources of water where it would be quickly washed away. Engineers knew that placing a sewer outlet drain by a water intake pipe would be

⁴⁸Without doing a content analysis on the titles of the literature or the content within, the specific arguments and discourse cannot be determined. However, the presence of a discourse is sufficient to lead to the conclusion that information processing was occurring with regards to the effect wastewater and sewage pollution was having on lakes, rivers, and the social processing system.

a health problem, but they thought placing the two far enough apart would be sufficient to eliminate any potential hazards (Tarr, p.149).

A second source of noise stemmed from the belief that running water purified itself. Even after scientists discovered that running water didn't purify itself they believed that sewage would be diluted in the water, thereby eliminating any source of risk. In 1877, John Nichol and Charles Macritchie claimed in a report on a sewerage system for Quincy, Illinois that the Mississippi river was large enough and flowed fast enough to dilute and deodorize any sewage within a short distance of its release point. Massachusetts allowed sewage to be released in rivers 20 miles upstream of public use areas (Tarr, p. 149). However, society understood that polluted water was detrimental to the state of the system, and society also knew that polluted water was a direct effect of dumping sewage into water sources, which provides counter evidence to the belief that running water purified itself or safely diluted pollution.

There was also a debate about the adoption of combined or separate sewer systems. Separate sewer systems made it easier than combined sewers to extract sewage wastewater before it entered waterways. Unfortunately, most separate systems drained directly into waterways without treating its sewage discharge. Accordingly, the debate over combined vs. separate systems would have had minimal impact on the decision to dispose untreated wastewater in waterways.

Conclusion

It is evident that the first part of the hypothesis has tested negatively—the enablers of control were present in the development of a waste control technology and society continued to pollute the environment. It is also evident that noise plays a role in

the development of control technologies. There is evidence of a debate at the institutional level of control between health officials arguing for the protection of waterways and engineers developing the sewer systems arguing that the best disposal method is the fast method. However, even after the work of medical scientists in the late 19th early 20th century, such as Louis Pasteur, Robert Koch, and William Segdwick, who provided quantitative evidence linking wastewater pollution in open water sources to public health problems, sewer systems were still allowed to discharge into waterways. Accordingly, it can be concluded that society was aware of the effect it was having on the environment.

In addition, the debate over the uncertain water purification process did not delay the construction of sewer systems. And by time the debate over water purification processes was over the large scale technological and capital intensive sewer systems were already in place. This suggests that noise is a part of the rhetoric between actors within the social processing system as they attempt to build support for their position (Latour, 1987).

Another conclusion that can be drawn relates to the original research question, as opposed to the hypothesis. The original research question asks, *why have waste elimination controls failed to advance at a rate required to control the advances of the other system parts?* An inherent assumption of that question is that a healthy environment is necessary for the proper functioning of the social processing system. The assumption was made based on the belief that the social processing system is nested within the encompassing global environment; therefore it would be necessary to not just shift pollutants from within the social processing system to an environment external to the system because everything is connected through energy flows, but to prevent

pollutants from affecting future inputs from the environment. However, the development of sewer systems highlights an interesting situation.

The social processing system was able to buffer itself from the affects of a polluted environment by developing another control technology, water filtration. While sewage treatment plants could have been developed, they were extremely cost prohibitive and it would have only benefited cities downstream. In addition, cities would have to build water filtration plants as a safety measure against any potential pollutants that could enter the system from sources other than sewage. Accordingly, building sewage treatment plants would have taken capital resources away from the city or raised the taxes for residents. And any attempts to prevent factories from polluting waterways would have either forced factories to close down or imposed insurmountable challenges to the manufacturing process. For example, the city of Philadelphia unsuccessfully attempted to close down the John and James Dobson mill, which was the biggest polluter of the Schuylkill River, after arguments were made that closing the plant would cost the city \$10,000 in taxes and the jobs of 2,600 workers that earned more than a million dollars a year (Raufer, 1998). Thus, it was easier to filter the water coming into the city than it was to treat the wastewater before it entered the environment. To do the latter would have caused the social processing system to expend energy beyond what was necessary to maintain the system's ability to continually process energy. Accordingly, in the case of early wastewater elimination controls it can be concluded that waste control technologies did advance at a rate required to control the advances of the other system parts.

Chapter 4: Controlling Sulfur Dioxide

This chapter will cover the historical development of control over sulfur dioxide emissions in the United States from the early 1800s to approximately the 1970s. Sulfur dioxide was chosen as the subject of this chapter because it differs from the nature of sewer systems and wastewater on a number of counts. First, the previous chapter focused on the development of a single control technology (sewer systems), whereas this chapter focuses on the control of a pollutant without respect to a single controlling technology. Second, sulfur dioxide is an invisible gas that cannot be observed. In contrast wastewater can be visibly observed not only on entering the environment but also in the environment when it is at sufficient concentrations. Third, the burden of responsibility to limit emissions of sulfur dioxide typically falls on private industries, whereas municipalities were usually charged with the responsibility of eliminating wastewater from urban environments.⁴⁹ Applying Beniger's (1986) theory and testing the hypothesis in a considerably diverse case will allow us to see how well the theory and hypothesis hold up under different conditions. This comparison is important because Beniger's theory of control should be applicable to all concrete open systems and not just specific ones.⁵⁰

⁴⁹Under long-standing "polluter-pays" theory for correcting pollution externalities, private industries bear the burden of limiting their emissions of toxic pollutants into the environment, but the government is responsible for placing the burden and making it heavy enough, through regulation or pricing mechanisms, to force compliance.

⁵⁰Applying the theory and testing the hypothesis in a case study that varies markedly from the previous chapter could limit the external validity of this thesis. However, Beniger's theory of control is a macro theory that should be applicable to all cases of control over the flow of energy within a system. Therefore, any concerns about external validity should not be attributed to differences between case studies.

This chapter is structured along the lines of chapter three. The first part of this chapter will provide the historical events that led to the control of sulfur dioxide.⁵¹ The second part will define the variables and apply the analytical framework that was described in chapter two. The third part will draw conclusions with respect to this thesis' hypothesis.

Properties of Sulfur Dioxide

This short section is meant to provide readers with a basic understanding of what sulfur dioxide is, where it comes, and how it reacts in the atmosphere.

What is sulfur dioxide: Sulfur Dioxide (SO₂) is a gas that is non-flammable, non-explosive, colorless, and has a strong odor (most people can taste or smell sulfur gas at concentrations from .3 parts per million (ppm) to 1 ppm (Research and Education Association [REA], 1973, p.104).

Where does SO₂ come from (Anthropogenic) and (Natural): It is produced by burning fossil fuels (primarily coal), refining petroleum, smelting ore that contains sulfur, etc. The trend in SO₂ emissions has gone from numerous small source point polluters (e.g. as heating fuel in home furnaces) to large source point polluters (e.g. coal fired power plants, smelters). Volcanic activity is a natural source of SO₂ emissions.

Secondary forms of SO₂: Sulfur dioxide is a primary pollutant, but once released into the environment it can react with other elements to form secondary pollutants. Sulfur dioxide can combine with oxygen to form sulfur trioxide ($2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$). Sulfur trioxide can combine with water to create sulfuric acid ($\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$). Sulfuric

⁵¹Air pollution, as a whole, has a long history and various movements within to control the different kinds of smoke pollution. There was the general removal of visible smoke, and other nuisance smokes. This chapter will be predominantly focused on issues concerning sulfur dioxide emissions.

acid deposition, commonly referred to as acid rain, can be precipitated in the environment in dry or wet forms.

Commercial uses of sulfur dioxide: It can be used as a reducing or oxidizing agent or as a catalyst in chemical processes. It is also used as a captive intermediate in the production of sulfuric acid and in the pulp and paper industry. Sulfur dioxide can also be used as a “fumigant, preservative, bleach, and steeping agent for grain in food processing; catalyst or extraction solvent in the petroleum industry; flotation depressant for sulfide ores in the mining industry; intermediate for bleach production; and reducing agent in several industrial processes” (Agency for Toxic Substances and Disease Registry [ATSDR], 1998, p. 110).

Historical Background

The quality of air that society breathes is a direct result of what people put in it. In that way, air quality is similar to water quality and the environment as a whole, whereby the environment is only as clean as the outputs society releases into it. Unfortunately, society puts enormous amounts of pollutants into the atmosphere. And as established in the previous chapters, the health of the social processing system is partly determined by the inputs received from the environment. So it should be no surprise that an estimated 70,000 people a year die from air pollution (Fischlowitz-Roberts, 2002).

Air pollution is not a recent phenomenon that started with the industrial revolution. In London, Edward I (1272-1307) banned the use of sea-coal, which was used extensively by blacksmiths and lime burners, because of its foul smelling emissions. Later, Edward II (1307-1327) had people who were found guilty of polluting the air with noxious fumes tortured. Afterwards Richard II (1377-1399) tried to tax the use of coal.

Henry V (1413-1422) established a commission to regulate the entry of coal into London. When Dante Alighieri saw sulfur miners in Sicily melting the sulfur out of the ore he was inspired to write *The Inferno* (Wilson, Colome, Spengler, Wilson, 1985). Around 1661, the diarist John Evelyn wrote this about the air in England,

“It is this horrid smoke, which obscures our churches and makes our palaces look old, which fouls our clothes and corrupts the waters so that the very rain and refreshing dews which fall in the several seasons precipitate this impure vapour, which with its black and tenacious quality, spots and contaminates whatever is exposed to it” (Evelyn 1661, as quoted in Wilson et al., 1985 p. 2).

These historical examples of air pollution do more than provide anecdotal evidence of early environmental conditions. They underscore the continuing and enduring nature of air pollution.

The first air pollution problem addressed in the United States was smoke pollution. Smoke pollution became a significant problem in the United States after coal was adopted as the primary energy source for material processing, heating, and transportation. Although smoke pollution was as long-standing a concern as water pollution, it took considerably longer to construct any type of control system. Joel Tarr (1996, p. 14) suggests the reason was because smoke pollution was seen as a nuisance pollution, rather than a health concern. Many physicians suspected the negative health impacts of smoke, but it was difficult to establish cause and effect. Conversely, a few physicians and laypersons thought smoke to be of some medical benefit. Around 1890 the Polk County clerk of Tennessee described Ducktown, TN as a health resort.⁵² The

⁵²Ducktown, TN was a mining community that received large amounts of smoke pollution from the nearby Tennessee Copper Company and its smelting operations.

clerk was also quoted as stating that “sulphor smoke is very conducive to health, and adds much to the healthfulness of the country” (Quinn, 1993, p. 583).

Air pollution from sulfur dioxide has been around for as long as people have been burning fossil fuels. Sulfur dioxide’s pungent odor, which is described as the smell of rotten eggs, was probably the odor that Edward I sought to eliminate when he banned the use of sea-coal. Dante was likely subjected to the pungent smells of sulfur dioxide when he witnessed the sulfur miners in Sicily around the start of the 12th century. In 1852 Angus Smith discovered that burning coal produced sulfuric acid that was precipitated by rain in Manchester England.⁵³ Twenty years later Smith published the book *Air and Rain: The Beginnings of a Chemical Climatology* (1872). From the middle of the 19th century to the early 20th century, smelters, and particularly ores that contained sulfur, were substantial contributors of sulfur dioxide emissions.⁵⁴ During this time sulfur dioxide pollution from smelters was blamed for the destruction of forests and crops, and health problems for people and animals.

Around 1895 citizens in the Appalachian Copper Basin brought lawsuits against two regional mining companies (Ducktown Sulphur, Copper and Iron Company, DSC&I; and Tennessee Copper Company, TCC) over sulfur smoke pollution (Quinn, 1993).⁵⁵ The primary offense committed by the two companies was their use of *heap roasting* and its subsequent release of sulfur dioxide gases. Roasting is a metallurgical process that removes part of the sulfur content from mined ores by a process of oxidation. There are

⁵³Burning coal does not produce sulfuric acid directly. Burning coal produces sulfur dioxide, which later oxides in the atmosphere to sulfur trioxide and sulfur trioxide combines with water in the air to create sulfuric acid.

⁵⁴Smelting is the process by which metals are removed from their ores.

⁵⁵The Appalachian Copper basin is located at the southeastern corner of Tennessee and encompasses parts of Georgia and South Carolina.

various ways to roast mined ore, but DSC&I and TCC employed heap roasting, whereby ore was piled onto a bed of cordwood and then ignited. The burning piles of cordwood and ore were left to roast for one to three months (Quinn). During that time plumes of sulfur dioxide gas would continuously pour out from the heap. In 1904 the courts decided in favor of the plaintiffs, awarding them damages, but the court did not stop DSC&I and TCC from polluting. The court's justification was that the companies were roasting their ores in the best known fashion and the activity was taking place in as remote a place as possible. The court's decision shows the attitude that the social utility of certain economic activities outweighed environmental concerns.

In 1904 the state of Georgia started legal action against the state of Tennessee and the two mining companies. However, the legal action was halted when TCC and DSC&I agreed to stop heap roasting and adopt a new form of roasting called pyritic smelting, which was suppose to alleviate the sulfur dioxide problem. The pyritic smelting method allowed the mined ore to be roasted in ovens, which allowed smoke to be captured and sent up smokestacks and released high into the air where it could be diluted by natural wind currents, while heap roasting released its smoke at ground level.⁵⁶ However, the Pyritic smelting enabled the mined ore to be roasted faster than it was with heap roasting, so more ore was processed, which meant more sulfur dioxide was released into the atmosphere, thereby negating any positive effects of increased height in atmospheric dispersion—evidence of the dialectic between processing speeds and the need for more control. In addition, the higher release point in the atmosphere increased the geographical area that was affected by the plants' emissions (Quinn, 1993).

⁵⁶TCC built a 325 foot tall smokestack and DSC&I built a 70 foot smokestack (Quinn, 1993).

In 1915 the Selby Smelter Commission (SSC) published a comprehensive 500 page report on the effects of air pollution from the Selby Smelting & Lead Company in California (Holmes, Franklin, and Guld, 1915). The Selby Smelter Commission was created to settle a dispute between the residents of Solano County, CA and Selby Smelting & Lead Company.⁵⁷ The commission was formed on May 22, 1913 and took two years to investigate the claims of both sides (Holmes et al., 1915) The findings of the commission will be discussed later in the paper, but for now it's important to note that there was a consensus among experts that sulfur dioxide was detrimental to the well being of the physical environment. Problems arose over sulfur pollution when it came time to establish cause and effect between the anthropogenic activities of man and the environment.

The Selby Smelter Commission report was published in 1915, and the commission published its results in a thoroughly scientific manner. The commission published the results of the surveys, experiments, their methodology, and an annotated bibliography of related literature. Despite the commission's rigor, in 1926 Lily Weierbach published an article critiquing the current methodology of measuring the effects of sulfur dioxide on plants (Weierbach, 1926). In Weierbach's critique, she makes specific reference to the Selby Smelting Commission and claims that the Commission's methodology for measuring sulfur dioxide in the atmosphere was inaccurate.

⁵⁷On July 16, 1908 the residents of Solano County, CA were awarded an injunction against the Selby Smelting & Lead Company (Holmes et al., 1915). However, in March of 1913 the residents claimed that Selby Smelting & Lead Company was violating the terms of the injunction. Rather than go through the expensive process of litigation, the two sides agreed to adhere to the recommendations of a mediator (Holmes et al., 1915). The Selby Smelter Commission was an impartial mediator made up industry experts, academics, and government officials. The commission was charged with investigating the allegations between both parties and separating fact from fiction.

Forty years after the publication of Weierbach's (1926) study, the problem of measuring cause and effect between sulfur dioxide and vegetation was still plaguing farmers, scientists, and the accused polluters. In 1966 Harold Wolozin and Emanuel Landau published an article titled *Crop Damage from Sulfur Dioxide*. In the article they claimed that the negative affects of sulfur dioxide on vegetation had been known for decades. Yet, the authors lamented the fact that the only recourse for a remedy for affected farmers was the court system. "This recourse to the courts, it should be emphasized, was the only avenue for recovery of damages to growing plants and forest trees by smelter operations, and its effectiveness was a direct function of the 'state of the arts' in assessing the damage due to SO₂. Therefore, in one sense, the abatement problem has always been in part a measurement problem" (Wolozin, Landau, 1966, p. 395).

Aside from the visible degradation of crops from sulfur dioxide, the article raised the possibility of sulfur dioxide degrading the nutritional value of crops. If there were non-visible damage to the nutritional value of the crop, the true market value of the crop would not be reflected in its price—a market diseconomy.⁵⁸ Wolozin and Landau (1966) describe SO₂ pollution as a "classic example historically of a technological external diseconomy. The smelter which emitted the gas bore almost none of the costs. The agricultural industry, which suffered the results of the offending process, initially bore the entire cost; for there was no incentive for the smelter to use preventive devices to minimize the real cost to the farmer of the waste disposal" (Wolozin, Landau, 1966, p. 395).

⁵⁸Another study published in 1978 claimed that "the effects of SO₂ at concentrations insufficient to produce visible injuries remains uncertain" (Crittenden, Read 1978, p. 34).

The statement “use preventive devices” by Wolozin and Landau (1966) is partially misleading because it implies that devices existed for abating SO₂ pollution. As of 1966 there were some techniques for reducing SO₂ emissions, but they were unreliable and not applicable in every situation. For example, producers of SO₂ emissions could slow production to limit emissions, but this was economically impractical and there were no examples cited of an industry successfully adopting such a practice. Industries could also use meteorological forecasting to predict when atmospheric conditions would aid in the dilution of emissions. The most common technique was to construct tall smokestacks so that emissions could be diluted high in the atmosphere before reaching the ground level (although this technique increases the geographic region affected by SO₂ emissions). Another technique was to capture SO₂ and use it in the production of sulfuric acid. The Tennessee Copper Company used this technique to end the litigation with the State of Georgia. It should be noted, however, that this technique was not applicable for all producers of SO₂. Tennessee Copper Company had the unique fortune of being located next to a natural market for sulfuric acid (Quinn, 1993), and TCC had access to a quality of ore that permitted sulfuric acid production.⁵⁹ In 1970, after reviewing the state of research and technology available for flue gas desulfurization (FGD), the National Academy of Engineering stated that “contrary to widely held belief, commercially proven technology for control of sulfur oxides from combustion processes does not exist” (National Academy of Engineering – National Research Council, 1970).

Fortunately, as a result of many factors, SO₂ emissions decreased 50% from their 1973 peak of 31.7 million tons (U.S. short ton) to 15.7 million tons in 2003 (Jenkins,

⁵⁹“The southeastern United States had a major fertilizer industry, and, at the time, the greatest demand for sulfuric acid was in the fertilizer industry” (Quinn, 1993, p. 593).

Roy, Driscoll, and Buerkett, 2007). While there are many reasons for the decrease in emissions, many of them are related to the Federal Government's regulation of sulfur emissions. These regulations included the 1970 Clean Air Act Amendments, the 1980 Acid Rain Act, and Title IV of the 1990 Clean Air Act Amendments. Together, these led to improved flue gas desulfurization technologies (wet scrubbing, dry scrubbing, coal washing), the adoption of fuels containing less sulfur (low-sulfur content coal, natural gas, geothermal, hydropower), and increased public awareness of environmental problems attributable to SO₂ emissions.⁶⁰

Given the data presented so far, one might draw a number of conclusions. First, it would appear that control over sulfur dioxide had to wait for advances in technology. Another tempting conclusion is that externalities or diseconomies related to the cost of pollution and the maximum profit seeking nature of businesses stifled pollution abatement (see Gerhardt, 1968). One might also conclude that it took legislative action to force advances in technology (see "*Forcing Technology*," 1979). As we shall see, all of these conclusions can be subsumed within Beniger's (1986) theory of control. From this perspective we can see that they are related to control theory. For example, the increased public awareness, the legislative actions, and the technological advances are all examples of control programs—public awareness at the cultural level, legislative actions at the organizational, technical advances at the mechanical level, and alternative fuel adoption at the organizational and mechanical level.

Applying the Analytical Framework

⁶⁰Public attention was called to problems of air pollution after several disasters resulted in thousands of death. See Cassell (1968) for a description of the events that happened in "Meuse Valley, Belgium, 1930; Donora, Pennsylvania, 1948; London, 1952 and 1962; and Poza Rica, Mexico, 1950" (Cassell, p. 201).

The relational hierarchy of environments, systems, programs, and control in the development of control over sulfur dioxide emissions

The environment: For this chapter, the system is the social processing system. Therefore, the environmental domains include the hydrosphere, the lithosphere, and the atmosphere surrounding the social processing system. Also, the pollution being examined (SO₂) in this chapter affects all three domains of the environment, whereas in the last chapter wastewater only affected the hydrosphere and lithosphere.

The system: The system is the social processing system, which includes all elements of society—institutions, factories, laws, people, buildings, etc.

The program: There is no one program of control that is being examined in this chapter. Instead, this chapter focuses on the evolutionary development of control over sulfur dioxide emissions.

Control: Broadly stated, control is the purposive regulation of sulfur dioxide emissions from anthropogenic activities. The broad definition of control frees it from the constraints of specific terminology, which means it can be used to identify programming mechanisms across the four levels of control (see table 2.1).

Measuring the Variables

Reciprocal communication: This will be measured by looking at the flow of communication between controller and controlled. The feedback loop will be determined as present or not present by determining if there was direct feedback between controller and controlled or indirect feedback as *mediated* through the four levels of control (genetic, cultural, organizational, mechanical).

Information processing: Information processing is the comparison of current states to future states. As such, information processing will be determined as present or not present by looking to see if informational inputs from the environment were compared with the desired future state and outputs of the system. The indicators of such activity will be publications in professional journals, institutional reports and memos, scientific reports, and literature reflecting cultural beliefs.

Noise in the communication process: Noise will be determined by looking for disputes over information or about the relationship between the health of the system and sulfur dioxide emissions. Noise will be examined through the four levels of programming.

Data

Reciprocal communication

Increasing the height of smokestacks was one of the first programmed responses to controlling sulfur dioxide emissions.⁶¹ At the start of the industrial revolution many factories had smokestacks that did not extend much higher than the factory roof. This led to enormous levels of pollution in areas surrounding factories. In response, factories extended the height of their smokestacks to allow the pollution to be diluted in the atmosphere. (The tall smokestacks approach is similar in form to early sewer systems.)

After increasing the height of smokestacks society needed a way to measure the program's effect on SO₂ emissions. Chemical analysis of the atmosphere is the primary method of detecting sulfur dioxide in the environment. Yet, chemical analysis only determines the extent to which sulfur dioxide is present in the atmosphere and not the pollutant's affect on the environment. In a modern example, chemical analysis is similar

⁶¹The phrase "one of the first programs" is used because King Edward the First's banning of sea-coal in London is an example of control at the organizational level.

to DNA testing used in court cases. A positive DNA test can place someone at the scene of a crime, but it doesn't prove that he did anything. To determine sulfur dioxide's affect on the environment scientists used controlled experiments. The experiments focused on the effects of sulfur dioxide on people, and plants (see Holmes et al., 1915; Weierbach, 1926; Crittenden & Read, 1978; and ATSDR, 1998 for a sense of chronological changes in experimental design).⁶²

Outside of the laboratory and chemical analysis, observant community members connected the proximity of smelters and coal burning facilities and their sulfurous smoke emissions to the visible deterioration of vegetation—reduced yield, discoloration, loss of foliage (Glass, 1979). Also, community members could smell or experience respiratory complications from the presence of SO₂—shortness of breath, nasal and throat irritation, eye irritation (ATSDR, 1998).

The observations of people linking anthropogenic activities to environmental deterioration were the first methods of feedback between controller and controlled. However, those observations had to be substantiated through chemical detection and laboratory tests before they could be accepted as valid observations (see the methodology used by the Selby Smelter Commission for determining the validity of the community member's claims of suffering from noxious fumes). The second method of feedback is through chemical analysis. However, chemical analysis does not establish cause and effect without controlled experiments. As a result of the simultaneous application of chemical analysis and controlled experiments scientists could use the state of vegetation in the affected region as a source of feedback (i.e. environmental indicator).

⁶²Latour (1987) comments on the epistemological consequences of laboratories separated from the natural environment. Latour raises the issue that it becomes difficult for dissenters to challenge information obtained in an experimental or laboratory settings as those experiments increase in complexity.

In summary, there were two main feedback mechanisms. The first was chemical analysis of the atmosphere. The second was the state of health for vegetation and community members. Both channels produced indirect feedback, with the former being at the genetic level and the later being at the mechanical level. Also, those two channels of reciprocal communication have been in existence since establishment of the first control program (tall smokestacks) and subsequent control mechanisms.⁶³ (Note, both methods relied on controlled experiments to correlate cause and effect between sulfur dioxide and environmental degradation.)

Before concluding that reciprocal communication was present between control mechanisms and sulfur dioxide emissions we must consider the limits of scientific observations and knowledge in early detection methods. By comparing the methodologies and conclusions of the Selby Smelter Commission, which was considered to be the most accurate report at the time (Holmes et al., 1915, p. 28), to more current methodologies and conclusions of current literature regarding sulfur dioxide, we reveal several discrepancies between historical knowledge and current knowledge.

First, data from the Selby Smelter Commission (Holmes et al., 1915) report states that SO₂ was undetectable by smell or taste at 1 ppm by 60 people. After additional tests concerning the smell or taste of SO₂, the report concluded that “the average person is conscious of pollution of the atmosphere by sulphur dioxide when its concentration is approximately 3.5 parts per million parts of air” (1915, p. 38). The conclusions of the SSC report in regards to a person’s ability to smell or taste the presence of SO₂ seem grossly underestimated when compared to more recent studies. In 1973 a source on pollution control technology stated that “most people can taste [sulfur dioxide] at

⁶³ Here we see the importance of scientific knowledge in regards to establishing fact from fiction.

concentrations from .3 ppm to 1 ppm” (REA, 1972, p. 103). In 1998 the Agency for Toxic Substances and Disease Registry published a comprehensive toxicological profile for sulfur dioxide, in which they stated that sulfur dioxide may possibly be detected between .3 and 1 ppm and easily detected at 3 ppm (ATSDR, p. 65).

Prior to the start of SSC’s data collection, the SSC stated that a review of literature regarding sulfur smoke “failed to disclose any methods for determining sulphur dioxide which, in the opinion of the commission and its staff, would satisfy the requirements of the proposed investigations.” (p. 28). So the SSC combined the best methods as described in the literature and created their own methodology that would allow for “instantaneous sampling, continuous or average sampling, a high degree of accuracy, and rapidity of execution combined with ease in field manipulation” (p. 28). Despite the SSC’s determination for scientific rigor, the study by Weierbach (1926) showed several possibilities of error in their methodology for measuring sulfur dioxide. Sources of error included variations in vapor pressure, difficulty of maintaining a partial vacuum, water vapor not acting according to Boyle’s law, the use of a rubber stopper, and the adsorption of sulfur dioxide by glass surfaces (p. 97-98).

In addition to concerns over the accuracy of SSC’s report, there were concerns over the study’s lack of scope. The only effect of SO₂ on people mentioned was our ability to smell or taste it. However, a number of studies have linked SO₂ exposure to shortness of breath, nasal and throat irritation, eye irritation, etc (see ATSDR, 1998). Also, the SSC (1915) report did not consider the effects of secondary pollutants from SO₂, such as sulfur trioxide and acid deposition. Consequently, controlled experiments could show that SO₂ must be present at levels well beyond that of the average ambient air

levels to harm plants. Therefore it became easy to conclude that SO₂ was not affecting plant growth. However, this approach did not account for possible secondary pollutants of SO₂ that damages the vegetation.

Based on the examples of scientific error described above, we can conclude that reciprocal communication between control mechanisms and sulfur dioxide emissions was *not* sufficiently present until approximately 1963 when more attention was given to secondary pollutants of SO₂, most notably acid rain.⁶⁴ By taking the secondary pollutants into consideration, the total effects of sulfur dioxide emissions could be understood. Without taking secondary pollutants into consideration it was possible to go to an area damaged by acid deposition and measure the presence of atmospheric SO₂, and after finding low levels of SO₂, to conclude that sulfur dioxide emissions had no effect on plant growth in that region; such a conclusion would be grossly misleading, yet accurate to the extent of our knowledge.

Information Processing

As stated in chapter three, a program can receive informational feedback from its environment, but if the program fails to act on that information it will be unable to maintain control over the flow of energy. In contrast to the case of sewage, in which there was reciprocal communication, in this case reciprocal communication is only partially present. Furthermore, information processing is dependent on the informational inputs received during the process of reciprocal communication. As result, if information processing is present in this case, it will be proportional to the reciprocal communication that was present between controller and controlled. In other words, society can only process information that is received, and the information can only be received if there is

⁶⁴The term 'sufficiently' is used to denote that partial feedback existed.

feedback between the controller and the controlled. After a review of several bibliographies pertaining to the effects of sulfur dioxide on the environment, it can be concluded that that information processing about the effects of SO₂ on the environment (as scientists understood those effects to be) was present.

The following references contain bibliographies that list numerous examples of information processing, some of which date back to the early 1800s. *Industry and the Environment in the Appalachian Copper Basin, 1890-1930* (Quinn, 1993); *Effects of Sulfur Dioxid Upon Plants: Methods of Study* (Weierbach, 1915); *The Effects of Air Pollution on Plant Growth with Special Reference to Sulphur Dioxide. I.* (Crittenden & Read, 1978); *Acid Rain: Rhetoric and Reality*, (Park, 1987); *Report of the Selby Smelter Commission* (Holmes et al., 1915); *Toxicological Profile for Sulfur Dioxide* (ATSDR, 1998); *The Acid Rain Controversy* (Regens & Rycroft, 1988); *Crop Damage from Sulfur Dioxide* (Wolozin & Landau, 1966).

Summary of Reciprocal Communication and Information Processing

In the previous two sections it was shown that prior to the 1960s scientists did not consider the secondary effects of SO₂ pollution. By not taking secondary pollutants into account scientists lacked the metrics or information to fully understand sulfur dioxide's effect on the environment. Starting in the 1960s, scientists began to understand the full extent of damage that SO₂ could have on the environment. Furthermore, information processing about the affects of SO₂ was present in the areas where reciprocal communication was present. Prior to the 1960s information processing mainly focused on the effects of SO₂ acting alone in the environment. Starting in the 1960s, information processing began to include the affects of secondary pollutants such as sulfur trioxide and

acid deposition. Accordingly, it can be concluded that the previous two data sections show a positive correlation between the establishment of control and the presence of information processing and reciprocal communication, which means that society did not knowingly pollute the environment. Instead, society lacked the metrics to understand the ramifications of large-scale sulfur dioxide emissions. Stated in terms of the null hypothesis, it can be concluded that a system of control did not develop in the absence of the enablers of control.

Noise

The hypothesis of this thesis states that control over waste elimination failed, in part, to develop because of a lack of information processing and reciprocal communication. In situations where the enablers of control are present and control over waste elimination failed to develop, the role of noise has to be taken into consideration. The independent variable is the enablers of control, which could also be considered co-variables. The dependent variable is the establishment of control over the elimination of waste. And noise is an intervening variable that is examined in when the enablers of control are present and control over waste elimination is not present.

As concluded in the previous section, the enablers of control were not present and a system of control was not developed for the elimination of sulfur dioxide—there is a positive correlation between the presence of the enablers of control and the establishment of control. As a result of the positive correlation, the role of noise does not need to be examined because the outcome was predicted by the first part of the hypothesis. Furthermore, the methodology section of this thesis explicitly stated the casualty is one

way, meaning the effect cannot influence the cause; likewise, the intervening variable cannot affect the independent variable.⁶⁵

Conclusion

It is evident that the first part of the hypothesis has tested positively—the enablers of control were not present and the development of control over sulfur dioxide emissions failed to develop. In addition, because of the lack of reciprocal communication between anthropogenic activities and the effect of sulfur dioxide emissions on all elements of the environment (biotic and abiotic), we can conclude that society did not knowingly pollute the environment. As evidence, I cite the previously stated conclusion that society only knew *some* of sulfur dioxide's effects on the environment. In further support, there is evidence that society applied measures of control in the areas where sulfur dioxide's negative impact on the environment was known. For example, society used mechanical means of control (pyritic smelting, tall smokestacks, sulfur dioxide sequestering) and organizational means of control (court injections, local regulations) to abate known local pollution problems as early as 1906. However, these means of control only minimized local problems of pollution and not the larger more systemic effects (e.g. acid deposition).

Given the tremendous amount of political and scientific debates sparked by acid deposition, some readers may wonder why this chapter doesn't give it more attention. The reason is because acid deposition did not become a significant source of interest for scientists until after 1963. At that time secondary pollutants of sulfur dioxide became of

⁶⁵It could be possible for noise to have an effect on the establishment of the enablers of control. However, this issue is not explicitly addressed by the theoretical framework. Therefore, conclusions about the effect of noise on the establishment of information processing and reciprocal communication would be circumstantial due to the absence of a conceptual framework explicitly developed to deal with this issue.

interest, thus leading to the completion of the feedback loop between anthropogenic activities and the effects of sulfur dioxide emissions. This conclusion can be reached by noticing the passage of several federal bills aimed at abating, among other pollutants, sulfur dioxide (Air Pollution Control Act of 1955⁶⁶ Clean Air Act of 1963, Air Quality Act of 1967, Clean Air Act Amendments of 1970, Clean Air Act Amendments of 1977), increased funding for scientific research, and the decline of sulfur dioxide emissions by 29% between 1973 and 1993 (Jenkins et al, 2007).

⁶⁶This was first federal legislation related to air pollution. Even though it precedes the date of 1963, the bill only provided research and financial assistance to states. Additional research would need to be done to determine if the legislation helped fund the study on acid deposition that was started in 1963 by Dr. Gene Likens and Dr. Herbert Bormann. Even if the bill was linked to enabling the start of Dr. Likens and Dr. Bormann's study, it could only be concluded that the bill helped enable the completion of the feedback loop, and not that the bill completed the feedback loop by itself.

Chapter 5 – Conclusion

This thesis started with a question in the author's mind as to why society has been so slow to address environmental pollution problems. Searching for the answer to that question, the author found much written on the subject of pollution control. However, most of the literature addresses the issue from within a societal context, whereby pollution occurs as a result of political disputes, market failures, or technological shortcomings. And despite the tremendous insights that can be gained from reading the various literatures on pollution, those books did not provide a sufficient answer to the author's question. Especially given that if the answer to environmental problems can really be found, as the literature suggests, in political reform, corrections to the market, or more technological innovation, why doesn't society do it? So to try and answer the same question that so many others have addressed, the author approached the problem of pollution control at a fundamental level, by applying Beniger's theory and looking at the very nature of control in concrete open systems.

The rest of this paper will serve as a reminder of the findings in the previous chapters, as well as point out the implications of those conclusions. In addition, this chapter will call attention to the limitations of this study and the areas within the scope of this study that could benefit from additional research. Finally, this paper will conclude with a brief open ended discussion of related and potentially connected areas in need of further research.

Summary of Findings

Based on the original hypothesis there are four potential outcomes that could have resulted.

- 1) A positive correlation between the variables, whereby the enablers of control are present and a system of control is in place.
- 2) A positive correlation between the variables, whereby the enablers of control are not present and a system of control is not in place.
- 3) A negative correlation between the variables, whereby the enablers of control are present and a system of control is not in place.
- 4) A negative correlation between the variables, whereby the enablers of control are not present and a system of control is in place.

Of the four outcomes, the first two are predicted by the hypothesis and accounted for in the theory laid out in chapter two. The third outcome is predicted by the hypothesis, but only by the introduction of noise as an intervening variable. The fourth outcome is not predicted by the hypothesis nor is it accounted for in the theory.

Of the four outcomes, the third one was found in chapter three, the first and second outcomes were found in chapter four, and there was no evidence supporting the fourth outcome as a conclusion.

Implications of this study

This thesis concluded that society has been slow to develop systems of control for waste elimination because it lacked two fundamental elements of control: information processing and reciprocal communication with respect to pollution. Of course, the aforementioned conclusion is on the verge of being obvious. For example, does it make sense to think that society can control something if that something is not part of a discourse (i.e. processing information related to it)? Does it make sense to think that

society can control something without seeing the effect of society's influence on that something (i.e. reciprocal communication)? Of course not. However, there are some novelties in the conclusions that were drawn in this thesis.

First, the conclusion extends the applicability of Beniger's theory, because Beniger only applied his theory to the areas of energy extraction, processing, transportation, and consumption; his theory is now extended to waste elimination. Second, the conclusion helps dull the arguments of those people lamenting society's willful destruction of the environment by positing that society suffers from its limited ability to forecast the environmental consequences of anthropomorphic activities. As the conclusion suggests, society's ability to forecast is related to our ability to participate in a reciprocal communication with the subject of control, and our ability to process information received during the feedback process. Finally, the conclusion does not discount other theories related to pollution and energy control. As it was explicitly argued in chapter four, the other theories related to politics, science, social values, and economics, can be subsumed within Beniger's theory. Therefore, the conclusion does not detract from, but adds to the other theories by placing them within a larger construct, thus giving the other theories access to new heuristic devices. For example, economists would have access to the dialectic narrative between processing speed and control, whereby they might be able anticipate future breakdowns in control by looking at how increased processing speed in one part of the system will affect the rest of the parts in the system. The ability to anticipate and prevent control failures seems especially important in today's globally interdependent economy. Arguably, the global society is struggling to

maintain control as a result of China's economy being able to extract, process, and consume more energy.

Limitations of this study

As with all studies, this one is not without its shortcomings. First, the study is limited in terms of its external validity because of the small number of observations. From the two case studies it seems appropriate to extrapolate a number of assumptions to other situations, especially since the case studies fit within Beniger's theory of control. However, given the complexity and sheer number of pollutants, having only two case studies means the conclusions should be applied to other theories with caution. Also, this study suffers from its lack of quantifying how much data is enough data to conclude that the enablers of control were present, which is a critique of Beniger too. To overcome this problem numerous examples of reciprocal communication and information processing were included in the data chapters. By overcompensating with data, hopefully, the critiques of not explicitly stating *how much data is enough* are reduced. Perhaps the greatest limitation of this study is that it's good at explaining macro-events, but not as good at explaining micro-events. To overcome this limitation it is necessary to augment Beniger's theory with additional theories. The technique of incorporating other theories was used by Beniger in his book, *The Control Revolution* (1986), and the technique of incorporating other theories is a hallmark of interdisciplinary research, which is also the nature of this study.

Additional Areas of Research

The analytical framework used in this thesis is designed for one thing, to test this thesis's hypothesis. As a tool, the analytical framework is invaluable. It allows the

author to focus in on the research question and tune out extraneous information.

Essentially the framework is a roadmap that helps guide the author to the paper's final destination, which are conclusions about the hypothesis. What's frustrating about the framework is that it doesn't allow the author to explore any of the interesting things he may find along the way. To the author, it's similar to saying *look but don't touch*, or *ask but don't answer*. Fortunately, this part of the paper lets the author share some of his observations and suggest how those observations might be explored.

The most interesting observation made while writing this paper concerns the social processing system's ability to place a buffer between itself and the environment. In chapter three it was noted that society was able to filter out polluted water, thereby mitigating the detrimental effects of polluted waterways on the social processing system. In turn, society was able to continue dumping wastewater into rivers and lakes without experiencing the pollutant's true effect on the environment. This raises some interesting questions. First, where in the evolutionary history of technology do filtration systems fit in? Are they similar to castle walls and moats designed to keep out potentially harmful inputs and let the good inputs in? Answering that question would help scholars understand filtration systems from a broader historical context. Second, consider the implications of creating an atmospheric filtration system similar to water filtration systems. Would such a technological system undermine the social utility of reducing air pollutants? In chapter three it was suggested that if society is able to filter out the effects of a pollutant then it downgrades the pollutant's threat to the social processing system. Stated otherwise, filtration systems prevent the pollutant from interfering with the social processing system's ability to maintain itself counter to entropy. In addition,

filtration systems might be preferred to preventing pollutants from entering the environment if preventing the pollutant draws more resources away from the rest of the system's parts than a filtration system would, which is precisely what happened in the case of sewer systems. It seems additional research needs to be done in the area filtration systems, with specific attention given to the way filtration systems protect the system from external environments, but also enables the system to neglect the consequences of its actions on those environments.

The role of noise in the development of control needs more attention from scholars too. As it was suggested in chapter four, noise may actually prevent the enablers of control from forming. The work of Bruno Latour (1987; 2005) and his development of actor-network-theory would be useful in that regard. The political process of building alliances and networks of power to promote the interests of social actors would likely result in several interesting findings, particularly through the act of retracing the use of science in the political process.⁶⁷ For example, what role does noise play in the development of the enablers of control. Does noise prevent feedback from occurring? A cursory examination of the question and data suggests yes, because of the amount of dispute that can arise over information and because information has to be mediated through one of the disputing groups before it can reach the controlling system, suggests that a dispute over information can prevent the circular flow of information.

This study could also expand the work done by Rosalind Williams (2000) and continue her study of how connective systems led to the inevitable destruction of the environment. Under Beniger's theory and with the idea of reciprocal communication and

⁶⁷See Latour's chapters titled "*Do You Believe In Reality? News from the Trenches of the Science Wars*" and "*A Collective of Humans and Nonhumans*" (Latour, 1999) for illustrations of what he calls the "political kidnapping of science" (Latour, 1999, p. 198).

information processing, connective systems are needed to enact control and thus mitigate the damage done to the environment. In a way, increased connectivity allows us to protect the environment, which is counter to Williams' argument.

Finally, another observation that was made was with respect to time delays in the application of knowledge. For example society began to make serious attempts at controlling the elimination of wastewater from cities in the 1850s. However, it took until the early 1900s, with the introduction of filtration systems, for a sufficient system of control to be enacted.⁶⁸ The 1960s marked society's first major attempts at controlling sulfur dioxide emissions. And yet again, it took almost 40 years before substantial gains were made in that area. Applied to the current issue of global warming, the observed time delay in chapters three and four suggests that it will take 40 years or more before significant progress is made towards limiting greenhouse gases.

Making an assumption about carbon dioxide based on sulfur dioxide and wastewater controls seems unrealistic, as it doesn't take into account new methods for developing systems of control. Currently, the most effective control over sulfur dioxide has been the cap and trade system established in Clean Air Act amendments of 1990. A similar cap and trade system could be used for carbon dioxide. In addition, access to scientific knowledge has increased exponentially, thereby increasing the speed at which feedback and information processing can occur. In theory, this should speed up and increase society's ability to control carbon monoxide. However, as it was shown in chapter 3, the establishment of control is dependent on noise, which means the political

⁶⁸Tarr (1997) provides data that shows deaths from typhoid fever actually increased as cities increased their networks of sewer systems, and that death rates from typhoid fever decreased as filtration systems were implemented (p. 189-90).

process between groups as they build support for their position will affect when and how control is actually established.

As it's been shown in this paper, society is a processing system comprised of interconnected parts that are highly reflexive in response to advances in control over the flow of energy into, throughout, and out of the society. The interconnectedness of society makes pollution control an immensely complex and necessary requirement for society. Failure to control pollution will push society closer to entropy. Conversely, excessive control over controlling pollution will take resources away from the primary, secondary, tertiary, quaternary, and quinary parts of the system, thereby degrading the system's ability to process energy. As a result, it seems that society must be cognizant of the interrelationship between the social processing system's components, and the fact that society is nested within the environment and not the other way around.

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