Modeling Information Flows Within A Nuclear Utility: A System Dynamics Approach

by

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ABSTRACT

Nuclear power accounts for a significant fraction of electricity generation in the United States. It is one of the safest and cleanest forms of power generation in the world. Yet, for all of its obvious benefits, it is one of the most publicly scrutinized technologies. The industry must always be looking to improve its safety and performance in order to lessen the adverse social and political factors that affect it. High-risk industries have learned that effective exchange of operating and near-accident experience information can be significant in improving safety and performance. However, the decision to implement a system to process information may increase labor costs and cause short-term losses in plant performance. Utility managers can access proven methods for analyzing and improving a plant's technology, but do not possess a tool to analyze and justify their decisions. These decisions not only affect the plant, but also the social and political environment in which it operates. Often these decisions are complicated by many non-linear feedbacks and time delays that can blind long-term effects. System dynamics provides a mathematical tool to analyze dynamic information-feedback systems and the consequences of policy changes in the systems. A nuclear utility system dynamics model has been created at Massachusetts Institute of Technology to analyze the impacts of a utility manager's decisions. This thesis adds an information sector to the model. This will provide managers with an aid to study the dynamic benefits and costs of information use at their utility. Adding this sector to the model will give it the ability to show the impact of information use on plant safety and performance, maintenance work, financial status and the social and political environment.

Thesis Supervisor: Dr. Kent F. Hansen

Title: Professor of Nuclear Engineering

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Chapter 1

1.0 Introduction

> [A good approach to system safety] is the application of engineering and management principles, criteria, and techniques to optimize safety within the constraints of operational effectiveness, time and cost throughout all phases of the system life cycle.
>
> (U.S. Congress-Office of Technology Assessment 1988, p.54)

Electricity generated by nuclear power lights more than one out of every five lightbulbs in the United States today. Because of limited natural resources, it would seem that using the 'splitting of the atom' to supply steam for electricity generation would be a smart choice for the future. However, because society feels that nuclear power places an unnecessary risk upon the general public, it has become a 'politically and socially' incorrect technology. Nuclear power will always be under constant scrutiny, so it must constantly improve in order to have an impact on our energy needs for the future.

Through increased research within both academia and industry, new and improved technologies have been developed to make the nuclear plants safer. For instance, the newly designed inherently safe reactors rely on gravity and natural circulation instead of pumps and valves for core cooling. However, up to now, there have not existed extensive tools to analyze the effect of policy decisions on plant operations and the social/political organizations that affect nuclear power. Management decisions, along with engineering changes, must be analyzed to see their effects on a nuclear power 'safety system.' Policy changes can have a significant impact on the social and political institutions which profoundly affect the acceptability of nuclear power in the present and the future. This thesis continues the work within the MIT International Program for Enhanced Nuclear Power Plant Safety that provides nuclear utility managers with a tool to analyze the effects of their decisions.

The nuclear industry has many organizations, such as The Institute of Nuclear Power Operations, that review the operating experience and near-accident information from the plants. These institutions form an extremely important Safety Information System (SIS) that process this information into reports which are made advailable to the industry. Each utility uses this information differently. Can the use of the information positively affect plant performance and safety? What are the short and long term effects of implementing an internal safety information system? Should the system include both inside and outside information about problems? Can the costs of this system be offset by increased income from better performance? This thesis studies the impact of utilizing outside information on the performance and safety of a nuclear utility. A better understanding of how to use this information and the costs of using it might reveal a way to further improve industry performance and safety, making it more competitive and appealing in the future.

This chapter begins with a description of the background behind nuclear power and the origins of the public's fear of it. Case studies will be used to illustrate how information exchange is needed in high-risk industries to prevent major accidents from occurring. Avoiding these accidents is of primary concern in the nuclear industry, as they can create adverse social/political effects on the plants. How can utility managers justify and explain the costs and benefits of information use within a nuclear power plant? This thesis attempts to solve this problem. The system dynamics sector, built in this thesis and connected to the nuclear utility model, will provide an additional tool to utility managers in performing cost/benefit analyses of information use.

1.1 Nuclear Power and Public Fears[1]

All one hundred and ten commercial reactors operating within the United States are light-water reactors utilizing either a pressurized (PWR) or boiling water (BWR) design. A reactor, like a coal-fire boiler, is a source of heat for the production of steam. Water circulating through the core removes heat produced by fission within the reactor core. This heated water produces steam either by boiling at the top of the reactor or by circulating through a heat exchanger called a steam generator. Steam then turns a turbine that spins the generator, producing electricity. Thermal/steam systems of similar configuration generate over ninety percent of United States' electricity.

The use of nuclear fission to generate heat and steam is what separates a nuclear power plant from other thermal power plants. Nuclear fission occurs when an atom of a heavy element splits into two or more lighter pieces. Fission may be induced by striking a heavy atom with a neutron or occur spontaneously in an unstable element. Because the nuclear forces binding the heavier element are much less than those binding the lighter pieces, the splitting of the heavy atom releases tremendous energy. Commercial reactors primarily utilize uranium 235 with neutron induced fission. Uranium 235 is a naturally occurring, but rare isotope of uranium. (Natural uranium contains approximately 99.3% U^{238} and 0.7% U^{235}.) Two or more atoms of lighter elements are produced when a uranium 235 atom splits. One or more neutrons are also released. These neutrons may then proceed to split additional uranium 235 atoms, creating a chain reaction where neutrons released from a prior split proceed to strike and split additional uranium 235 atoms, releasing more

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[1] Section taken from Eubanks, MS Thesis, MIT, 1994 (with minor editing).

neutrons and so on. If the chain reaction is self-sustaining, not growing or decaying (that is each uranium fission on average produced one additional fission), then the chain reaction is said to be critical. Commercial power reactors operate at criticality. The energy released by uranium 235 fissions heats the cooling water which eventually drives the generator.

The hazard to humans comes primarily from radiation, which can kill, cause cancer, or damage genetic material. Unstable, energetic atoms often break apart emitting energy, mass or both. The process of coming apart or emitting energy is called radioactive decay. Although there are many forms of decay, three are most common: alpha decay, beta decay, and gamma decay. Alpha decay occurs when a nucleus spits out two protons and two neutrons (a helium nucleus). Beta decay occurs when an atom spits out a high speed electron. Gamma decay occurs when an atom, instead of emitting mass, releases a burst of electromagnetic energy in the form of gamma rays. Alpha particles, beta particles and gamma rays are nuclear radiation; atoms which emit radiation or materials containing such atoms are said to be radioactive. Harm to humans, or any living thing, occurs when radiation enters or passes through the body and interacts with living cells. The energetic particles or rays can kill or damage living cells. If the genetic structure of reproductive or fetal cells is damaged, birth defects may occur. However, to kill or damage enough cells which would immediately kill or seriously injure a person requires an extremely large dose of radiation, many orders of magnitude above background radiation.

Unfortunately, radiation is an inherent feature of nuclear fission. Radiation may be emitted during the fission process, by radioactive fission products (lighter elements created by the fission process), by radioactive decay products, or by irradiated materials. Because shielding and distance virtually eliminate any direct offsite exposure from the reactor vessel, the danger of public exposure comes not from direct radiation being emitted by the operating reactor, but from the potential of an accidental offsite release of radioactive material. Although rare, equipment failures and human error have resulted in accidental releases. For over ten days in 1986, radioactive material spewed from the Chernobyl site in the Ukraine, causing wide spread exposure and concern. Twenty-nine power plant workers and firefighters died of acute radiation exposure and over 135,000 people within a twenty mile radius were evacuated. By far the worst reactor accident in world history, Chernobyl lacked many of the safety systems required in the U.S. However, even in the U.S., small releases have occurred. In 1979, Three Mile Island released small quantities of radioactive gases, producing very small exposures for the general public -- probably less than a third of yearly background exposure (Wolfson 1991, p. 198). The worst accident in the U.S. history, Three Mile Island, released less than a millionth the radiation that Chernobyl did (Wolfson 1991, p. 77).

> Is nuclear power safe ? Yes: Multiple safety systems ensure that radiation will be contained even when malfunctions and operator errors occur. Major accidents are possible, but are so unlikely that the risk is negligible. You are far more likely to die in an automobile accident, a fall, or a fire than in a nuclear accident. And no other industry can match the safety record of the U.S. commercial nuclear power enterprise (Wolfson 1991,p.209).

Although a nuclear accident may be the public's dominant technical concern with nuclear power plants, there are other technical issues inherent with the nuclear power industry which also concern the public. Operating a nuclear power plant produces unwanted radioactive materials. These materials are generally classified as waste and must be dealt with in some manner. Like all hazardous waste, radioactive waste raises environmental and human concerns. Two classifications of radioactive waste exist: high level (highly radioactive) which is primarily spent fuel, and low level (somewhat radioactive), which covers everything from irradiated tools to contaminated clothing. High level waste creates the greatest concerns because it is highly toxic to living beings. Currently in the U.S., no satisfactory means exist for dealing with long term storage of these materials, although a storage facility at Yucca Mountain in Nevada is under investigation. Low level waste is also still of some concern because it is generally buried at low level waste depositories, where it is to remain until no longer an environmental or health threat. Although nuclear power plants are not the only source for both high and low level wastes (weapons programs, hospitals, universities, and other sources produce both types), waste is an operational hazard of the industry.

Although the technical hazards associated with nuclear power ignite much of the public's concern, the public's fear over nuclear power has many origins. The threat of nuclear bombs and the images of destruction are always present in the nuclear debate. The horror of Hiroshima and Nagasaki has ingrained a fearful image of nuclear technology in people's minds. Even though the complete failure of a nuclear power plant could never produce the destruction of a nuclear bomb, the imagery persists. Real connections to the bomb do exist. However, typical commercial reactors are ill suited for weapons development. Bombs require either plutonium or highly enriched uranium, and commercial fuel is enriched only 1 to 5 percent. Spent fuel contains some plutonium which could be removed if reprocessed. However, commercial reactors are not designed for plutonium production, and reprocessing is a difficult and expensive endeavor. Thus, imagery and reality mix to connect the destruction of nuclear warfare to the energy production of commercial power reactors.

Societal perceptions of modern technology and social power also contribute to public concerns over nuclear power. The impersonality of the machine, the regularity of modern industrial society, and the complexity of advanced technologies alienate many within the public. The general frustrations and hostility toward the advance of technology are projected onto the nuclear industry. Aversion to the centralization of social and political power also becomes symbolized in the nuclear power plant as economies of scale have led to huge thousand megawatt concentrations of electric power generation. As Weart asserted, "Reactors became a condensed symbol for all modern industrial society" (Weart 1991, p.35).

The building and operation of nuclear power plants presents a highly charged public controversy. As discussed, real risk and the imagery of nuclear technology combine to create public concerns and fears. These in turn drive social efforts to control and direct this technology.

1.2 Safety Information Systems

Safety Information Systems are enacted in most high-risk industries today. The purpose of these systems is to make operating experience and near-accident information available to everyone within the industry. Studying others' operating experiences can help to improve work practices and procedures within one's own business and studying near-accidents can help to identify precursors of major accidents. Because full-fledged catastrophic events rarely occur in high-risk industries, near-accident scenarios must be studied to obtain information about large accident causes. (Tamuz 1994, p. 72). In both the airline and nuclear power industries, there have been catastrophic events that could have been prevented had SIS's been more actively used before the events occurred. These events show that information exchange is an extremely important element for the prevention of major accidents in high-risk industries.

1.2.1 Airline Industry - DC-10

In the late 60's, McDonnell-Douglas, attempting to regain a foothold in the jumbo jet market, introduced the DC-10 jumbo jet airplane. There is a consensous in the industry that this plane endured more problems and scrutiny than any other aircraft before it. (Fielder 1992, p. 2) In general, it was designed poorly with many vulnerabilities that would surface in its years of operation. One of the most vulnerable parts of the DC-10 (and most large aircraft, in general) was the cargo doors. Unexpected opening of these in flight causes rapid depressurization within the cargo hold of an airplane. In jumbo jets the floors are designed to function with equal pressure from the cabin above and the cargo hold below, so a depressurization in the cargo hold will cause collapsing of the floor. The DC-10 was designed with all of its control and redundant safety systems in the cabin floor, making it more vulnerable to depressurization problems than previous airplanes.

Throughout the design process of the plane, the manufacturers of the cargo door locking system (Convair division of General Dynamics) notified McDonnell-Douglas of the possible faults with the system. Some of these were that the visual check for locking of the door was subject to much human error, and the unreliability of warning lights about the door position. Convair was prohibited from directly communicating with the Federal Aviation Agency (FAA), and McDonnell-Douglas submitted reports without highlighting these faults to the FAA for approval (Fiedler 1992, p 85).

This problem became even more apparent in the DC-10's first ground test. In 1970, the first plane built was undergoing ground tests for its maiden flight. During a test of the airplane's air conditioning system, the cargo door flew open, and the floor collapsed because of the pressure differences in the cabin. Douglas did decide to make a few modifications to the locking system, but the modifications did not improve the ability of the operator to test the locking of the door. This gross error and others were able to get past the FAA because they neither had the manpower or expertise to inspect everything that went into an airplane. In July of 1971, the DC-10 received certification from the FAA. The Windsor incident occurred less than a year later after certification.

The Windsor incident was the first of many accidents that the DC-10 would endure. During flight, the cargo door compartment separated from the aircraft, causing rapid depressurization within the cabin. The floor failed, causing control cables to be severed and control of the tail systems was lost. Because of great pilot skills, the aircraft was landed without loss of life. The National Transportation Safety Board (NTSB) reported that the probable cause was the improper locking of the cargo door. The NTSB recommended that a modification should be made to the locking mechanism to make it physically impossible to improperly lock the door. The FAA responded with a 'gentleman's agreement' with Douglas that the planes would all be fixed according to service bulletins. This agreement came about because the FAA did not want to hurt sales of the DC-10, an American product. An airworthiness directive (AD) was not issued for the modification. An AD is as strong as law, and states that a plane may not be operated in violation of it.

These modifications in the service bulletin were not carried out on Ship 29. In March of 1974, this plane crashed near Paris, killing 350 people. The cause of this accident was almost identical to the Windsor incident. Finally, after this, the FAA issued an AD to insure that the correct modifications.

1.2.2 Nuclear Industry - Three Mile Island

In 1979, the accident at Three Mile Island (TMI) in Pennsylvania occurred and changed the face of nuclear power forever. The accident was a sequence of equipment failures and operator mistakes that eventually led to core melt, and release of contaminated coolant from the containment building. A simplified sequence of events at TMI is as follows:

- Pumps supplying feedwater to the steam generators shut down
- Emergency feedwater system turned on, but a closed valve prevented the water from reaching the steam generators. The closed valve was not noticed by the operators.
- The Pressure Operated Relief Valve (PORV), a valve that opens to release excessive pressuriser pressure, stuck open, releasing needed coolant to the containment floor
- Steam generators boiled dry, so reactor coolant heated and expanded, so pumps automatically began pouring coolant into the reactor
- As a result of more operator error, these pumps were shut down and the core began to disintegrate from lack of coolant.

(Tomain 1987, p. 1-2)

Events at other plants warned the Nuclear Regulatory Commission (NRC) that an accident of this nature was possible. However, the causes of the events were not studied completely or distributed effectively to prevent them from occurring at other utilities. Had they been looked into with more depth, it is possible that TMI may have been avoided completely.

The Inspection and Enforcement (I&E) division of the NRC is responsible for grouping together of information from past events, learning from these events and presenting the issues to industry. However, due to the deficiencies within the I&E division, these tasks were not performed effectively in the years preceding the TMI accident. Some of these deficiencies were:

- the absence of any procedure for systematic evaluation of the operating information that I&E receives
- apparent inability to resolve safety concerns within the NRC
- I&E's perpetuation of deficiencies originating in the licensing process.

(President's Commission 1979, p. 96)

Another noteworthy deficiency was that the I&E relied on the utilities and vendors to monitor themselves and report their own problems. Unfortunately, these responsibilities were not handled efficiently. All of these deficiencies combined to blind the NRC (and hence, the industry) from possible accident scenarios like the one at TMI. Near-accident events with precursors similar to TMI had occurred previously. Yet, because of the I&E's shortcomings, the nuclear industry was not made aware of them.

In 1974, a Westinghouse plant in Switzerland underwent a stuck PORV valve failure very similar to the one at TMI. However, due to the logic of the safety systems in the plant, its operators were able to identify the problem and correct for it. Westinghouse did not inform the NRC of the accident until after TMI had occurred, almost 6 years after the incident. Granted, the TMI plant was constructed by Babcock and Wilcox, and did not have the same emergency core cooling logic as the Westinghouse system. Nevertheless, had the operators been aware of the stuck PORV valve condition in the Switzerland accident, they might have not misdiagnosed their problem, which caused them to take actions that worsened the event conditions.

Another accident similar to TMI occurred at Davis-Besse (owned by Toledo Power) in 1977. The key element of the accident, the operator shutting down the high-pressure injection (HPI) system, was not even reported to the NRC. The utility provided a report explaining the operator's actions explaining that "...operator action was timely and proper throughout the sequence of events" (Supplemental Report from Toledo Edison in President's Council 1979, p. 104). The I&E division did not perform a separate study of its own, so the actions were reported to be correct. However, as we learned from TMI, they were not the correct actions to take in response to the situation. A regional NRC inspector expressed great concern about the implications of the event. He understood that the Davis-Besse operators did in fact shut off the HPI too early, but was told that the NRC was satisfied with the results of the Toledo Edison report. He was able to set up a meeting to discuss his fears with the Commission, but it was only a few weeks before TMI, too late to inform utilities of possible problems. In the accident sequence at TMI, the operators repeated the incorrect actions that occurred at Davis-Besse. They should have been aware that their actions were the incorrect ones to take.

1.2.3 Nuclear Industry - Post Three Mile Island

The Three Mile Island accident had dramatic effects on the nuclear industry. The NRC increased it regulations, public awareness heightened and there was an increased need for a stronger national presence by our nuclear utility industry. (Smith 1989, p.55) Most importantly, the nuclear industry was able to see many of its faults, and took numerous actions to improve itself. Of most importance was the impact of TMI on information exchange within the industry.

The NRC became more involved by increasing analyses and inspections, notifying plant of possible problems or solutions, and making utilities and vendors more responsible for reporting of issues and events. Vendors became more directly involved with the NRC and other organizations, and more public with their findings. The Energy Power Research Institute (EPRI) became increasingly involved in improving maintenance practices and studying advanced reactors. The World Association of Nuclear Operations (WANO) was created after Chernobyl as an organization of nuclear power plant operators around the world to encourage better communication and comparison among operators (Smith 1989, p. 56-57). The National Energy Institute (NEI) was recently formed from other national nuclear organizations (NUMARC, NPOC) to assist utilities in interactions with the public, Congress, the NRC, and other significant groups. The utilities also joined forces and realized that they 'are only as good as their worst performer' to form the Institute of Nuclear Power Operations (INPO).

INPO was created nine months after the TMI accident with the mission of "...promoting the highest levels of safety and reliability--of promoting excellence--in the operation of nuclear plants" (Moore 1989, p. 399). INPO's membership and sponsorship consist of all U.S. nuclear utilities and vendors. It was created to enact many of the programs discussed in the President's Commission report of Three Mile Island. Some of these include: plant evaluations, training and accreditation, assistance efforts, and of significant note in this thesis, event analysis and information exchange. INPO set up programs such as Nuclear Network, a large database to share world-wide experience, and the significant event evaluations and information network (SEE-IN) that acts to collect and distribute information on off-normal events. INPO has become the most influential national nuclear organization today for improving plant performance through information exchange and other methods.

1.3 Problem

Making use of outside information does not come without costs to a nuclear utility. It takes large amounts of time and manpower to review and process the large amounts of available information. The question is how, and in what manner does information effect costs and performance in the nuclear plant?

The MIT International Program for Enhanced Nuclear Power Plant Safety, a project within the MIT Center for Energy Policy Research, is sponsoring research to study the factors that affect nuclear plant operation. Some of these factors include: maintenance practices, social/ political relations, financial standing, and management. These factors are all studied to see their impacts on a nuclear plant's safety and performance. The overall project goal is to model the functioning of a nuclear plant and its interactions with the external world, perhaps finding how best to interact with it. (Eubanks 1994, p. 17)

This thesis studies how information exchange can affect the safety and performance within a nuclear power plant. The goal is not to obtain an exact representation of the information system, but to represent the behavior and how it can positively or adversely affect the running of a nuclear power plant.

1.4 Method of Solution

The safety information sector is concerned with the effect of various associations and knowledge sharing activities on the utility. In order to represent the flows of information correctly, sectors external and internal to the utility are added to the model. The external sectors generate events within the industry and produce informational reports from these events. These reports will be produced by INPO, vendors, WANO, EPRI, and the NRC. INPO is modeled in a separate sector because it is considered the most active organization in the nuclear industry for exchanging information. Within the utility, operating experience, problem reporting and NRC regulation review programs are modeled. These programs disseminate information throughout the utility to improve safety and performance. After testing the information sector apart from the utility model, these sectors were incorporated into the main model. Examples of the connections to the model are: engineer allocation and costs, plant ratings, and most importantly, improvement in safety and performance by reducing defects and breakdowns. Integrating the information sector into the model should provide a means to justify the use or suspension of information exchange for the nuclear industry.

The model was developed from information gathered from various individuals at the sponsoring utilities. Numerous factors, such as time delays and engineer usage, are estimated as best as possible from these discussions. System dynamics has been programmed in many commercial software packages that allow for simple pictorial modeling. Model development was done on both IBM-PC and Apple Macintosh platforms using Ithink/Stella® codes produced by High Performance Systems (High Performance Systems, Inc., 1994).

This project began in 1991 by identifying the social and political factors that affect utility decisions regarding nuclear plants. During 1991-1992, Policy Influence Path (PIP) charts were developed to analyze the external stakeholders that affected utility decisions. These factors were developed further in an initial system dynamics model of a nuclear plant and the social factors that affected it. The last few years have been focused on modeling a more complete operating nuclear power plant, developing more intensive social/political interactions and creating the financial model. As stated earlier, this thesis focuses on building the information sector of the model. The overall model is divided into five sectors, shown in Figure 1.1.

The next chapter presents an overview of system dynamics, and a few examples to familiarize the reader with the methodology. Chapter 3 presents information about the current utility model structure. Chapter 4 presents the information sector model, in a detailed sub-sector by sub-sector description. Chapter 5 will present some simulations that demonstrate the use of the information sector. The final chapter summarizes the work, and presents some comments for future work.

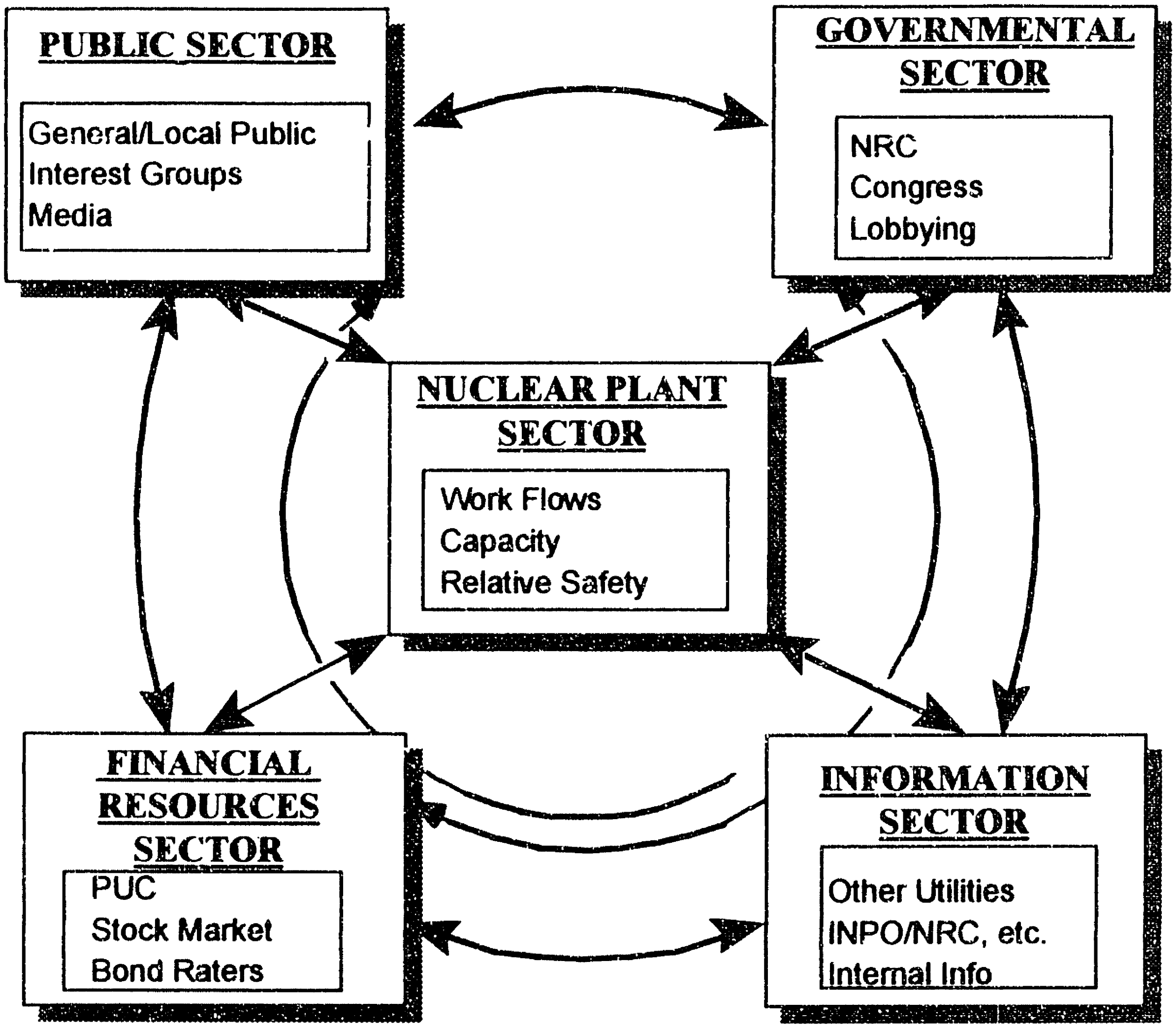


Figure 1.1: Model Sector Diagram
Arrows Represent Causal Connections Between Sectors

Chapter 2

2.0 System dynamics

> Managing our vast dynamic and complex social and technological society is a task that has become extremely difficult. Most of what we do these days is characterized by the enormity of its scale and the interrelatedness of all its elements. Stated succinctly: we live in a world where everything affects everything else.
>
> Brown (foreword in Forrester, 1975 p. vii)

In the mid-1950's, Jay Forrester and others at the Massachusetts Institute of Technology were involved in research that was aiming to integrate mathematics and science into the field of operations research. This was being done because studies were proving that previous research was not dealing with broad top-management problems effectively. Research began to develop in the field of relating engineering system analysis techniques to the management of complicated social systems.

> With simulation available [from lower cost computers] as a procedure for determining the behavior of a model system, it became fruitful to concentrate not on mathematical methods but on the fundamental nature of structure in systems. This work led to a simple and general structure that seemed capable of representing the interactions within any type of system. This generalized structure serves, not only as a framework for organizing observations and experience, but also expedites the simulation stage of system studies. (Forrester 1975, p.135)

Hence, the building blocks for the field of system dynamics were created.

The complexity of most business systems is too high for the human mind to completely understand. The systems are composed of numerous cause-effect relationships that can possibly induce counter-intuitive feedbacks on one another. These information-feedback structures are combined with time delays involved in each of the relations to create highly complicated systems. It is virtually impossible for a manager to predict the impact of a policy change on the future of his company, unless he is capable of understanding and simulating a complicated mental model. The development of system dynamics as a management tool has provided the manager with the ability to explicitly represent the system structure and simulate it over time to see the dynamic effects.

System dynamics models have been built and studied from everything to the Earth's population growth (Meadows, 1982) and the forecasting of new automobile markets (Urban, 1990). Models have been built by academics, businesses, and the government. They have all been built because the human mind is not capable of accurately predicting future behavior. The building of models helps to understand the system structure and can possibly lead to solutions for improving the performance.

2.1 Systems Thinking Approach

Humans typically approach problems and their solutions without taking into account feedback. Essentially, the feedback in a problem solving situation is understanding how

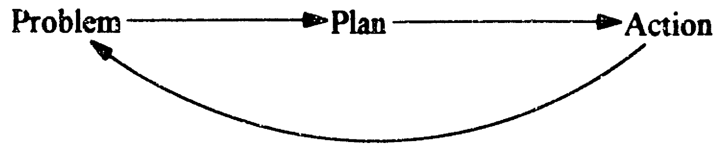


Figure 2.1: Thinking Approach Diagram
Open-loop and Closed-Loop Thinking Approaches

the solution or action effected the problem. Figure 2.1, problem solving for humans, shows feedback as the arrow from action to problem. (Richardson & Pugh 1981, p.5). The loop without the feedback from the action is know as 'open-loop' thinking, while the feedback loop is known as 'closed-loop' thinking. Closed loop thinking assists us in analyzing the effect of our actions on the problem, and forms the basis for being a systems thinker.

Identifying the structures and policies within the system is the key to system dynamics modeling. These structures must incorporate effects that influence the system and can, in turn, be affected by the system. Choosing the structures and policies in a system is called setting the system boundaries. These boundaries constrain the system to the desired cause-effect relationships. A good rule for determining the model boundary is that it should imply "that no influences from outside of the boundary are necessary for generating the particular behavior being investigated" (Richardson & Pugh 1981, p. 42). Basically, the unwanted and hence changeable behavior of the system must be included in the model boundaries. For instance, suppose a firm with fluctuating sales was being modeled. Obviously, sales rate and customer satisfaction would need to be incorporated into the model, but that probably is not enough to explain certain behaviors. It may be necessary to include such things as competitor's actions, market size variances, product lifetime, and service quality to fully understand the system and its fluctuations. However, it would be unnecessary to include obscure things, such as the phase of the moon, to represent the desired model behavior. In fact, putting in too many relationships within a system dynamics model can cloud the picture with external effects.

Once the boundaries of the system are set, it is necessary to begin to identify the relationships within the system. Typically, a 'laundry list' of key variables within the system is created to give a good scope of what to include in the cause-effect relationships. As an example, ask yourself 'What are a few factors that influence crowding in a public recreational area?' (example from Richardson & Pugh p. 161) A list of a few important factors can be created:

- Visitors per year
- Contact Area (area where people walk or leave their presence)
- Natural Area (area unaffected by people yet)
- Word of Mouth Advertisement of Area
- Total Area

This list provides the factors influencing the system, but does not explain how they are interrelated. A causal loop diagram is created to present the cause-effect relationships. For this crowding situation, a causal loop is shown in Figure 2.2.

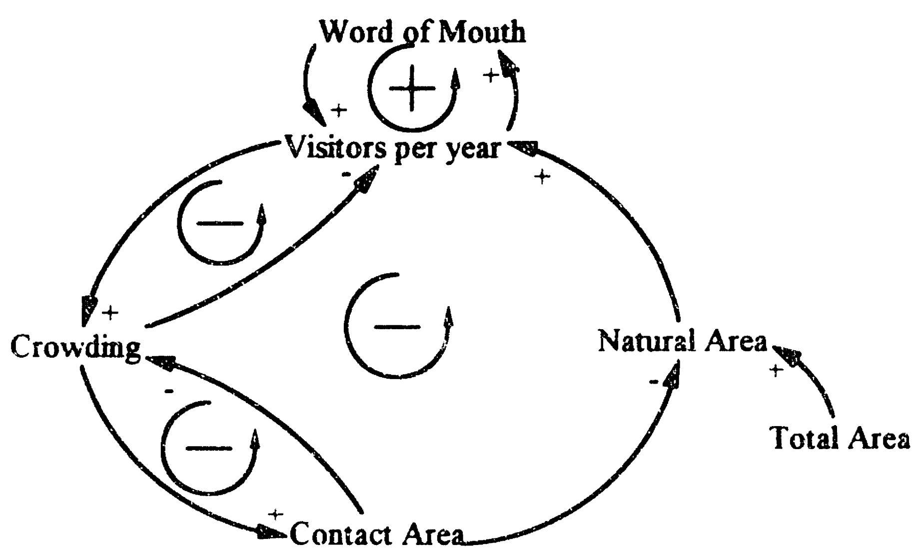


Figure 2.2: Causal Loop Diagram
Recreational Area Crowding

In causal loops the arrows connect the direct cause effect relationships, and the sign of the connection denotes whether it is a positive or negative connection. For example, a positive connection is when visitors per year increase, crowding increases. A negative connection is when contact area increases, natural area decreases. These cause-effect relationships are joined to create complete causal loops, in which factors that do not directly affect each other may indirectly affect one another through connections of cause-effect relationships. These loops can be classified as positive or negative. An example of a positive loop is that when visitors per week increase, word of mouth increases, and hence more visitors come to the park. The negative loop that is caused by park crowding, keeps the visitors down or balanced to a comfortable and enjoyable level. As this diagram shows, crowding is caused by both physical cause-effect relationships (land and people) and human cause-effect relationships (word of mouth).

Unlike linear modeling techniques, like a spreadsheet, system dynamics allows the building of feedback structures and time dependent problems. Building models can help to understand patterns of behavior and possibly control them. Building a model may not produce exact solutions to a problem, such as the optimal number of park visitors on February 14th, but it can provide understanding of relationships, behaviors and dynamics in systems.

2.2 Model Building Blocks

There are three important building blocks in system dynamics. They are known as: levels (stocks), rates (flows), and auxiliaries (converters). A level is "an accumulation over time, a storage device for material, energy, or information. Rates of flow increase or decrease the level accumulated." (Richardson & Pugh 1981, p. 176) Examples of levels are: water in a bathtub, the national debt, and population. Flows corresponding to these levels would be: drainage, expenditures, and births. Auxiliaries convert one type of flow to another or can represent relationships between different levels, flows or other converters. Examples of these would be converting an order rate to desired production rate or to depict a relationship between customer satisfaction (level) and sales (flow).

System dynamics models are combinations of stocks, flows, and converters that are assembled to represent the causal loops as best as possible. Feedback from the levels controls the flows. In turn, these flows, through converters, can control other flows which will again change the stock levels. This creates a complicated dynamic feedback system, that if performed correctly, can produce an excellent system representation. The next sections illustrate different examples for modeling simple systems. The first, a scientific example of radioactive decay, will help to explain the use of stocks and flows more clearly. The second will be an example of a typical boom and bust sales scenario in new products.

2.3 Radioactive Decay Model

The radioactive decay model development will help to understand the use of stocks and flows within the Ithink® model format. Simple causal loops, Ithink® diagrams, and charts will be shown to represent the decays. Three decay cases will be presented, and each will add onto the Ithink® model. They will be linear decay, radioactive decay of one element, and chain radioactive decay. For this example, the imaginary elements and arbitrary half lives to be used are element A (10 week half life), B (20 week half life), and C (stable element).

2.3.1 Linear Decay

One can imagine a situation of draining a bathtub at a constant rate. This is analogous to the first example of linear 'decay' (we know that atoms do not really undergo this type of decay). A causal loop of this situation is displayed in Figure 2.3.

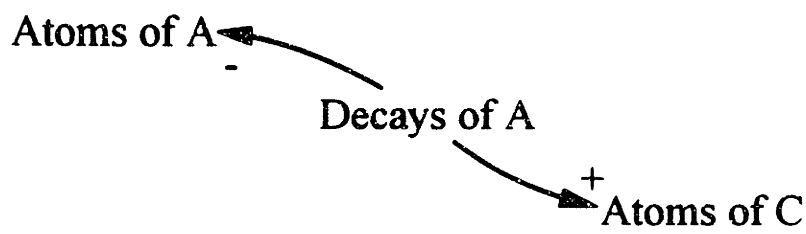


Figure 2.3: Causal Loop Diagram
Linear 'Decay'

Because the decay rate is constant, there is no feedback in the system. Figure 2.4 shows an Ithink® representation of this example, in which the atoms of A and C are stocks, and the decay is a flow. For this example, there are initially 1000 A atoms, and they decay at a rate of 20 atoms/week. Figure 2.5 shows the results of the simulation.

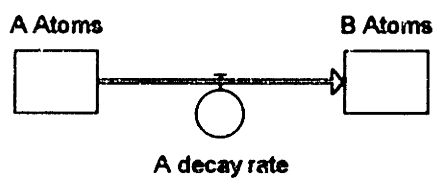


Figure 2.4: Ithink® Diagram
Linear 'Decay' From A to C

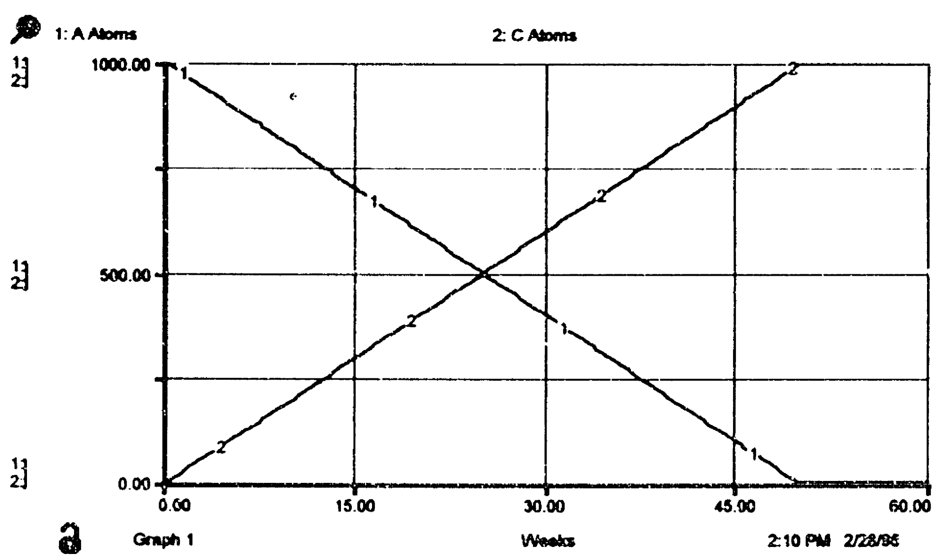


Figure 2.5: Linear Decay
Linear Decay and Growth of Atoms A and C

As expected, A linearly decreases while C increases at the rate of decay of A. Notice that the flow from A is stopped when atoms of A no longer exist, as would also be expected.

2.3.2 Exponential Decay

Radioactive decay is actually an exponential process. This occurs because the decay rate is the number of atoms multiplied by the probability that an atom will decay per unit time (decay constant). The causal loop diagram in Figure 2.6 now depicts this feedback on decay, forming a balancing loop that causes the decay rate to be dependent on the number of atoms that will decay.

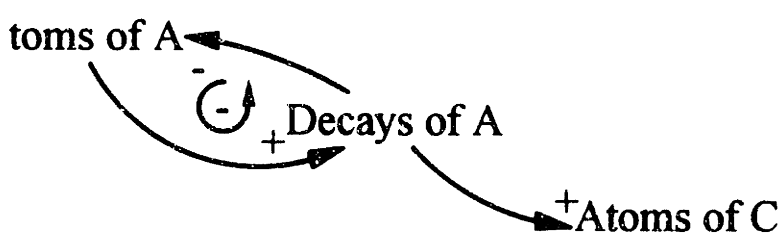


Figure 2.6: Causal Loop Diagram
Radioactive Decay

This negative loop is apparent when the equations governing this decay are studied. The equation for the decay rate now becomes:

$$-dn(t) = l n(t)\, dt \qquad (2.1)$$

where $n(t)$ is the number of atoms at time t

and l is the decay constant with $l = ln2/T_{1/2}$.

The exponential behavior is more apparent when the equation is integrated to become:

$$n(t) = n_o e^{-lt} \qquad (2.2)$$

where n_o is the initial number of atoms.

In a system dynamics stock and flow model the equation for the flow is represented by Equation 2.1, and the resultant level of the stock will follow the behavior in Equation 2.2. The Ithink® diagram of this situation is shown in Figure 2.7.

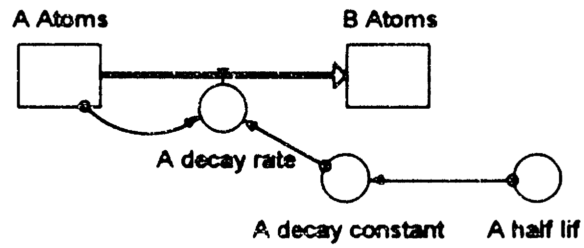


Figure 2.7: Ithink® Diagram
Radioactive Decay from A to C

Notice that the stock of A atoms is now connected to the decay to represent the feedback of atom level. The half life ($T_{1/2}$) is also included in Ithink® so that the decay constant can be calculated. The formula for the flow is:

$$A\ decay = A\ decay\ constant * A\ atoms \qquad (2.3)$$

When simulated, this equation is multiplied by the time interval, so it is equivalent to Equation 2.2. The results from this simulation are shown in Figure 2.8 and Exponential decay occurs, as expected.

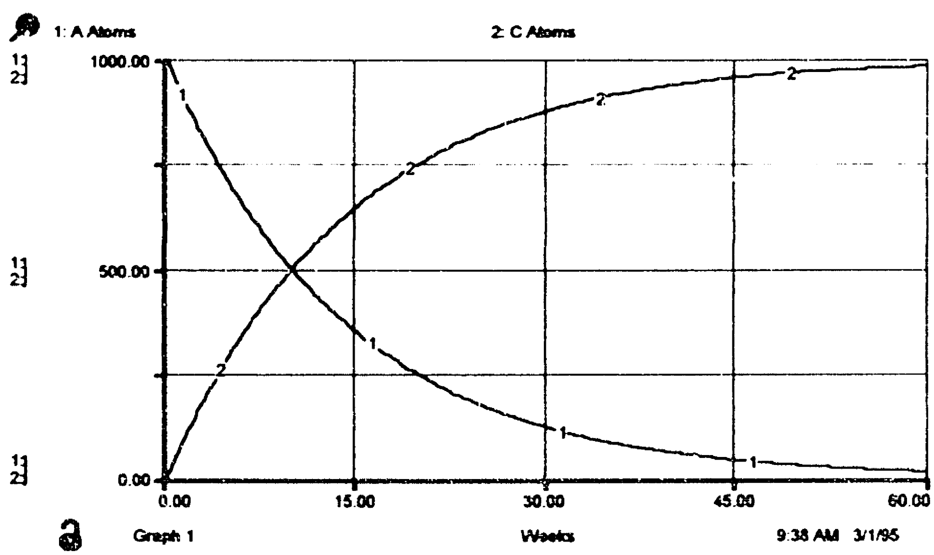


Figure 2.8: Radioactive Decay
Exponential Decay from A to C

2.3.3 Radioactive Chain Decay

One other interesting radioactive decay is chain decay. Chain decay occurs when one atom decays to another which then decays to a stable atom. In this example it will be A decaying to B which then decays to the stable C atom. The causal loop diagram of chain decay is shown in Figure 2.9.

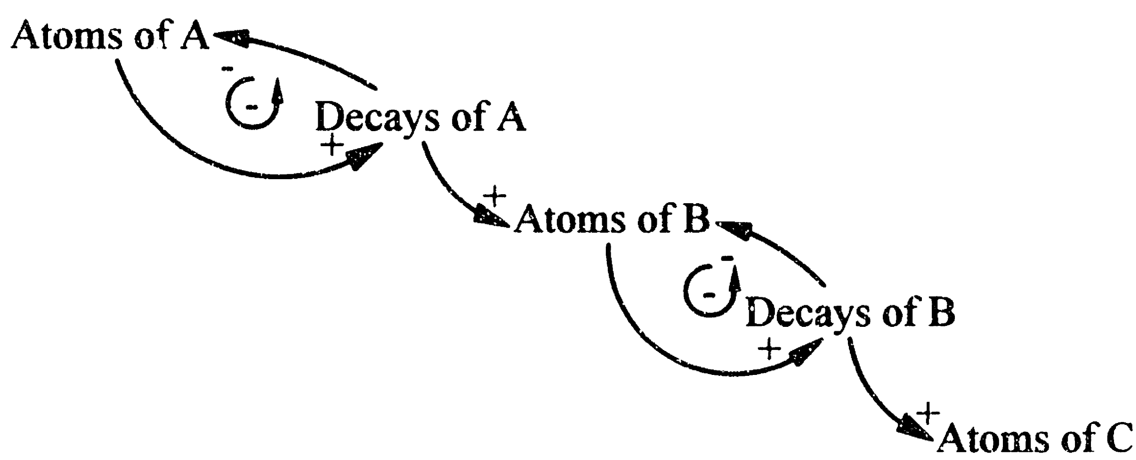


Figure 2.9: Causal Loop Diagram
Chain Radioactive Decay

Consectutive delays are extremely common in information-type systems. For example, a design is created by an engineer (1st delay) but then is sent to a manager for before the project is carried out approval (2nd delay).

It is apparent from this diagram that there will be two flows connected to the stock of B atoms. These will be the decay of A (creation of B), and the subsequent decay of B (creation of stable C). Each of these flows are part of the formula representing the net flow of B atoms:

$$dn_B = -l_B n_B \, dt + l_A n_A \, dt \tag{2.4}$$

where the subscripts correspond to the atoms.

The first part of the formula represents the decay of B and the outflow from the B atom stock. The second is the inflow, the decay of A. This is diagrammed in Ithink® as shown in Figure 2.10. Notice that the stock of B atoms has both an inflow and outflow and that the level of the stocks again determines the flows (to create the negative loop).

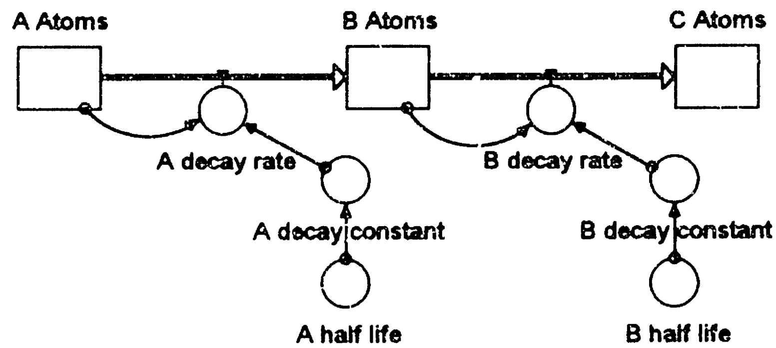


Figure 2.10: Ithink® Diagram
Radioactive Chain Decay

The results are shown in Figure 2.11. The A atoms decay just as they had done in the previous example, causing the number of B atoms to increase. Eventually those atoms decay to the stable C atom. The buildup of C atoms is dependant on the time constant for the decays of A & B.

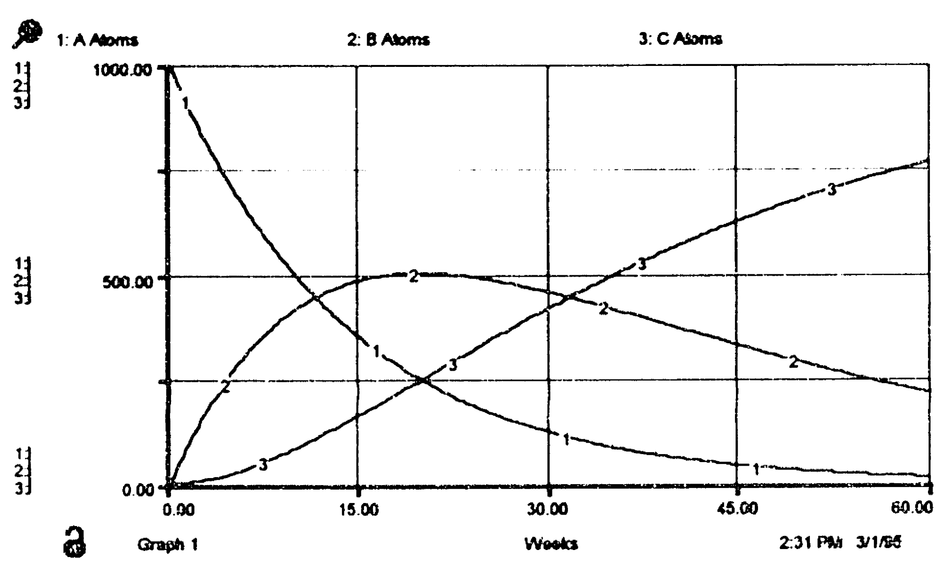


Figure 2.11: Chain Radioactive Decay
Chain Decay From A to B to C

Again, this chain decay is analogous to and information-type system in which a single system delay, such as manager approval, can retard the effectiveness of the system significantly.

2.4 Building a Simple Human Model - 'Boom and Bust'

In many industries, a phenomenon called 'boom and bust' occurs upon the introduction of a new product. As an example, consider the plights of Coleco and Atari. Both companies introduced new and exciting products into the market. One was a talking teddy bear, and the other a complete game machine. Both products experienced large sales growth and then quick declines. Neither company was able to predict the decline and both lost significant amounts of money because of overexpansion. The feedback that causes that boom and bust can be explained through a simple system dynamics model.

2.4.1 Sales With No Word of Mouth

One of the keys to generating sales of a product is advertising. Advertising can create interest in the products to turn non-customers into customers. Non-customers are people who have not shown interest in the product, and customers are purchasers of the product. This is represented in Figure 2.12. For the purpose of this example, it is assumed that spending a constant amount on advertising produces a constant rate of sales, and the base of non-customers does not grow.

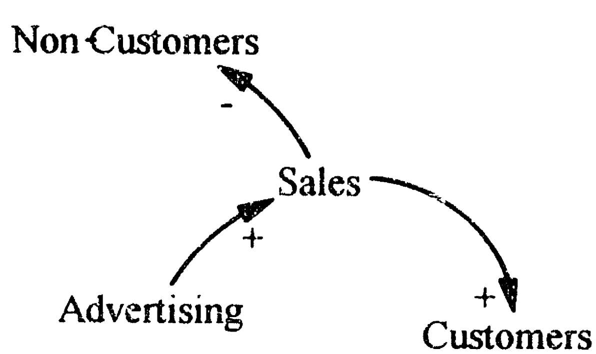


Figure 2.12: Causal Loop Diagram
Sales Without Word of Mouth

This situation is analogous to the linear decay model. Non-customers (the market size) will decrease linearly and customers will increase. The behavior is obvious, so it is not necessary to show the results of simulation. As long as the customer base is big enough (non-customers exist), sales will be constant, and it will be easy to choose production rates, staffing, etc.

2.4.2 Sales With Word of Mouth

One of the largest contributions to sales is generated through word of mouth interactions. When a customer interacts with a non-customer the interaction can produce a sale. For example, talking to your neighbor about a new lawnmower may influence you to purchase a new one also. Word of mouth creates a positive and negative loop in the sales model, as shown in Figure 2.13.

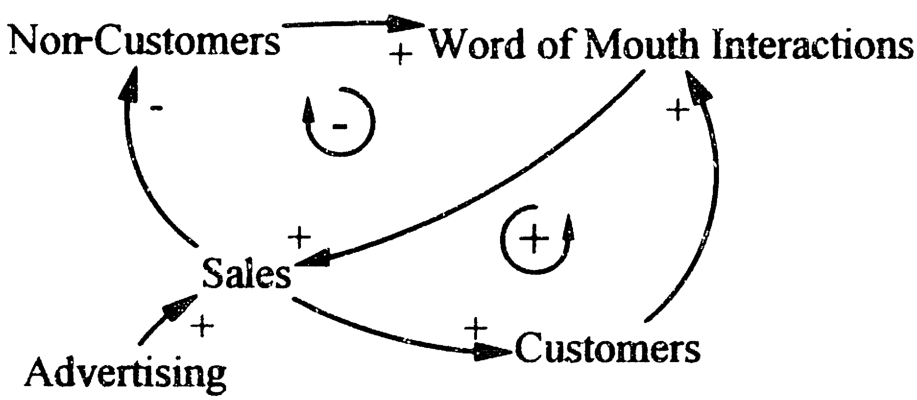


Figure 2.13: Causal Loop Diagram
Sales With Word of Mouth

The positive feedback increase sales when interactions are frequent, and the negative feedback decreases sales when non-customers decrease. This situation is represented by the Ithink® diagram shown in Figure 2.14 in which the feedback loops are extremely apparent.

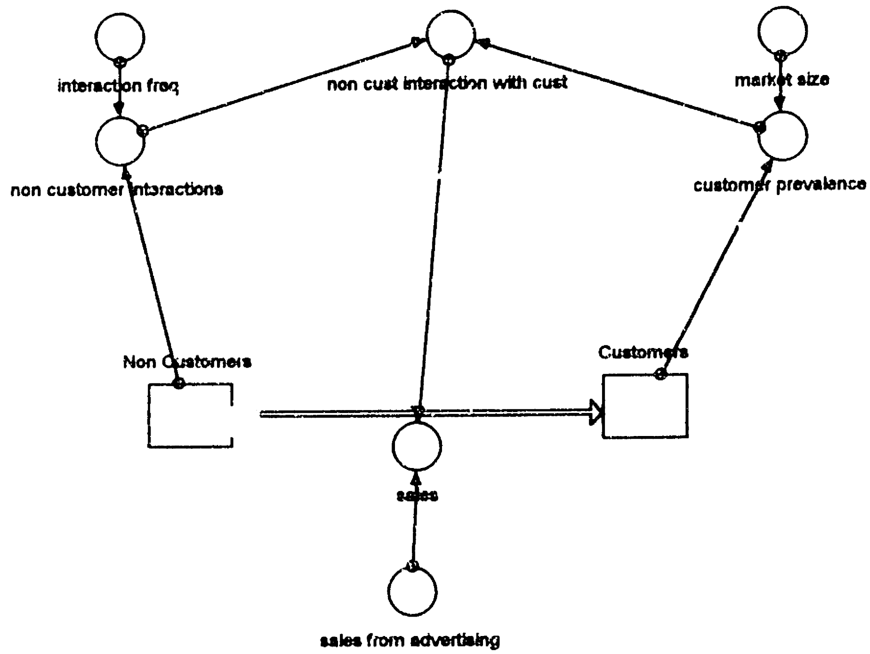


Figure 2.14: Ithink® Diagram
Sales with Word of Mouth Effect

The mathematical expressions for the variables and their corresponding units are listed below.

SI Initial Customers = 0
[customers]

SI Initial Non_Customers = market_size
[non-customers]

F sales = sales_from_advertising+non_cust_interaction_with_cust
[customers/week]

C non_customer_interactions = interaction_freq*Non_Customers
[potential customers/week]

C non_cust_interaction_with_cust=non_customer_interactions*customer_prevalence
[customers/week]

C customer_prevalence = Customers/market_size
[customers/non-customers]

V interaction_freq = .10
[1/week]

V market_size = 100000
[non-customers]]

V sales_from_advertising = 100
[customer/week]

The results from simulation are displayed in figure 2.15. Sales experience 'boom and bust' because they start out slowly, but then customer interactions with non-customers increase which causes a rapid increase in sales. Because of the limited market, the non-customer prevalence decreases and sales decline. This sales 'boom and bust' produces what is know as 'S-shaped' growth in customers. Behavior like this often causes mangers to believe that sales will keep increasing at the high rate, which can cause many poor decisions for production and company expansion. They often do not understand they are operating in a limited market. In order to prevent 'boom and bust' from happening, the company must introduce new products or formulate plans to increase the base of non-customers in the market. This extremely simple model depicts a reason why many new businesses today fail. Larger models, built correctly, can give even further insight to problems like these.

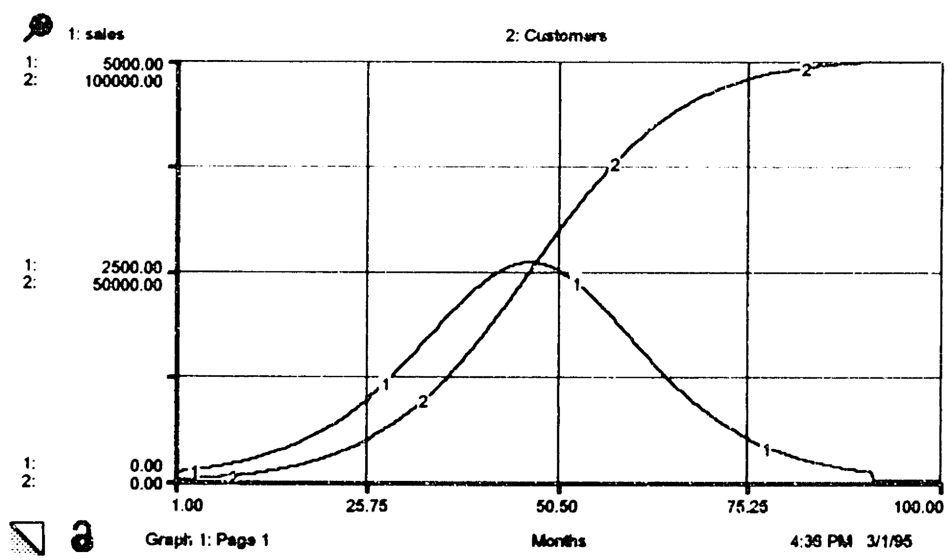


Figure 2.15: Sales Growth
Boom and Bust, S-shaped Growth

2.5 Model Validation

System dynamics models are built to simulate the real world and answer questions about various behaviors. A model can be built for numerous reasons, which can range from the general, as in studying and understanding system behaviors, to the specific, such as answering the question of the time to bring a product to market. Whatever the reason, models are built under the premise that they are considered valid when they serve the purposes of the builder. It would be "..meaningless to try an judge validity in the absence of a clear view of model purpose." (Richardson & Pugh 1981, p. 210) This purpose can sometimes be a very subjective goal, and is the largest source of conflict in the modeling community.

In the case with our nuclear utility model, much of the detailed data that would be necessary for exact behavior representation is unavailable as it is considered proprietary. It is our goal to have the model agree with the cause-effect relationships which are apparent in the industry today. Having the model represent behaviors accurately will serve the purpose of having an extensive nuclear utility model to exhibit interesting feedback from changes within our utility, industry and the social/political environment. The model will not be able to exactly predict the results of increasing inspections or cutting 25% of the labor force, but will produce the dynamics that result from these changes. Remember, that if the model serves our purpose, it can be considered valid for understanding behavior.

Chapter 3

3.0 Nuclear Utility Model

A system dynamics nuclera utility model has been under development at MIT. Its purpose was to provide utility managers with a tool to analyze the long-term impact of their decisions on the plant, social/political institutions and the financial environment. There are 5 main sectors in the nuclear utility model; public, governmental, nuclear plant, financial and information. This chapter will present the main causal loop for each sector, and describe the fimctions of each sector and their sub-sectors. The information sector will be discussed in detail in chapter 4.

Each of these sectors were built individually and then connected to the others. Connecting these sectors yields many nonlinear feedbacks and delayed responses, which makes the model difficult to analyze and explain. These feedbacks and responses create many unintended or counter-intuitive results, which can hopefully represent reality. Even at the level of sub-sectors, the feedbacks are difficult to explain in a paragraph. The 'budget allocator' or 'work allocator' mentioned throughout this discussion is the person who chooses budget and work parameters before running the model. Changing work and budget parameters are the means for altering plant behavior and studying responses to decisions.

3.1 Public Sector

The Social Sector includes local public, national public, media, and interest groups. Each of these groups provides a positive feedback on the others, which can lead to rapid saturation during a simulated accident. The strong positive feedback of this sector is shown in Figure 3.1.

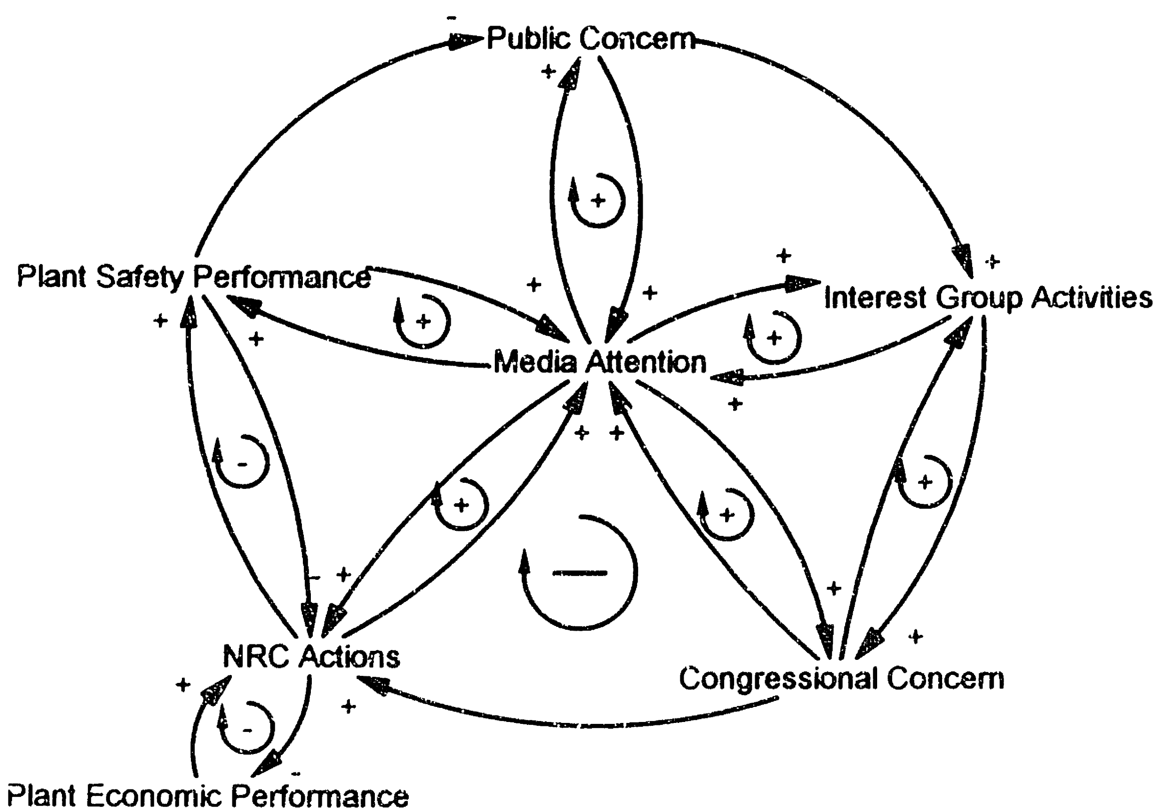


Figure 3.1: Causal Loop Diagram
Social and Governmental Sectors

3.1.1 Local and National Public Concern

Local Public Concern represents the public in the community served by the nuclear power plant. Local public concern is capable of being much more variable than national public concern because of the reactor's operating history, local goodwill efforts, and local politics. The local public has a direct effect on the Public Utility Commission (PUC), local media, stock prices, and interest groups. Local concern is heavily influenced by national concern, but the effect of an accident at another plant is not as great on local concern if the local utility has performed well.

National Public Concern represents the public at large. Its concern does not change as rapidly as local. However, its effect on the utility can be greater financially because of the possibilities for increased inspections, regulations, interest group lawsuits and media activity.

3.1.2 Media

The media monitors interest group activity, government reaction, utility operations and public concern. Based on these measures, the media produce reports and follow-up stories that influence the concerned groups again. This effect can cause a strong positive feedback.

3.1.3 Interest Groups

Anti-nuclear interest groups are constantly at work monitoring utility operation, government actions and public concern. These groups need funding to operate and as public interest grows, more people contribute. These contributions improve their ability to wage lawsuits, demonstrations and lobbying efforts. In some cases, these groups also have considerable influence on the PUCs.

3.2 Government Sector

The governmental sector concerns the actions of the national government. It includes the NRC, Congress, and SALP Ratings.

3.2.1 Nuclear Regulatory Commission

The NRC controls inspections, regulations and information transmission between utilities. After an accident, the NRC increases investigations, research and regulation production. Direct utility effects are mandatory inspections, worker distractions (because of NRC inspection work), and increased workload in the information sector. This sub-sector provides regulators with an opportunity to gauge effects of new regulations and inspections. The actions of the NRC work to appease Congress, media, the public and interest groups.

The utility can influence the NRC by investing in regulation abandonment, conducting its own inspections, or improving its SALP scores. The model provides a good method for testing the return on investment in each of these areas.

3.2.2 Congress

Congress is influenced by public concern, media, interest group lobbying, utility lobbying and NRC responses. As public concern increases, the number of concerned lawmakers increase. This increase directly affects the NRC influencing them to conduct more investigations and write more regulations. Congressional concern naturally decays as other issues enter the political field.

3.2.3 SALP

Safety Assessment and Licensing Procedures (SALP) sub-sector represent the calculation of the utility's SALP score. This score determination is done by the NRC and is based on Engineering, Maintenance, Operations, and Support factors. The engineering score is based on engineer workload and quality design specifications achieved for parts. The maintenance score is determined by mechanics workload and broken equipment. Operations is based on training, forced outage frequency and operator astuteness. Support is based on Manager workload and information usage. The model does not calculate all of the factors that enter into SALP scores, such as operator drill performance, security, or safety analysis performance. These additional factors are assumed to average and have the effect of reducing the range of the SALP somewhat.

3.3 Nuclear Plant Sector

The plant model is composed of thirteen different sub-sectors adapted from the Dupont Maintenance model. The plant sector is primarily concerned with deriving the capacity of the plant based on various inputs such as personnel allocation, discretionary inspections, learning curves, and inventory control. The plant model can be used to determine the value of preventative maintenance (PM) and to test methods for gradually implementing a successful preventative maintenance program (PMP) with limited resources. The causal loop of the plant sector is shown in Figure 3.2. The negative feedback loop of capacity is the most important. It is effected by breakdowns, equipment wear & tear, and maintenance.

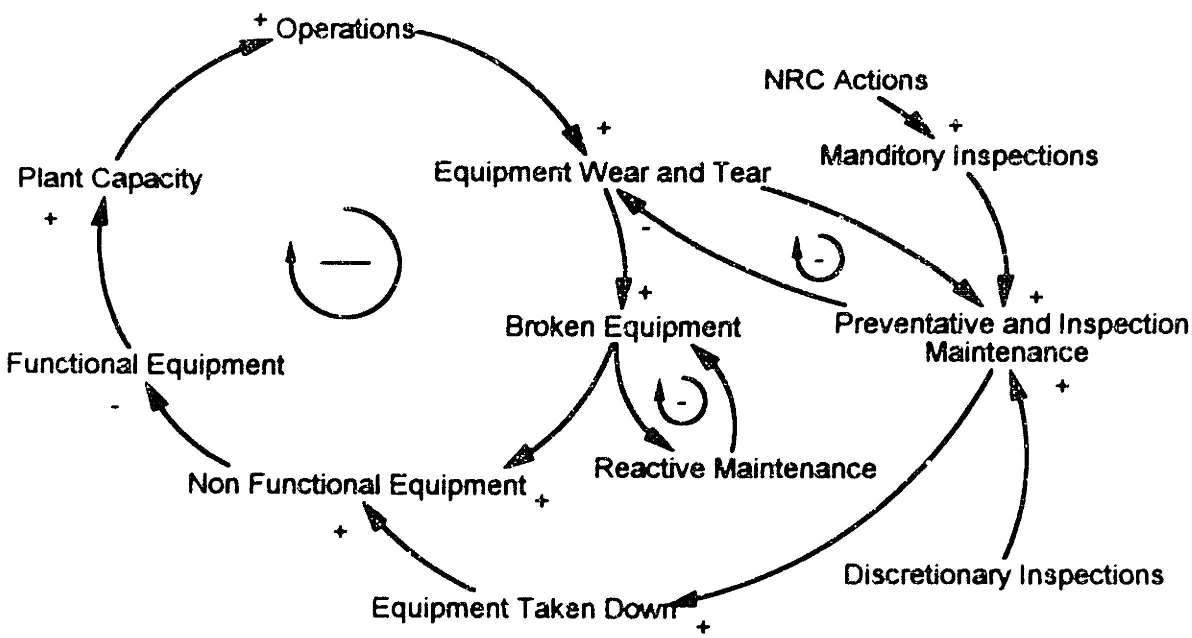


Figure 3.2: Causal Loop Diagram
Nuclear Plant Sector

3.3.1 Equipment Flows and Capacity Calculation

The equipment flow sub-sector controls the total pieces of equipment either fully functional, broken down, or taken down for PM. The flows among the three states is controlled by the other sub-sectors within the plant, such as equipment repair rate, inspection rate, and breakdown rate.

The capacity calculation is a graphical function based on percentage of equipment broken down or taken down by maintenance personnel. If equipment is taken down, it is expected that some prior planning has occurred so that it does not affect capacity as severely. The chance that broken equipment will cause a forced outage is accomplished with a probability function. As more equipment breaks, the probability of one of those piece's causing a forced outage increases. Periodic outages also effect capacity in this sub-sector.

3.3.2 Defect Flows

The defect flows sub-sector generates defects, produces breakdowns, and eliminates defects through repair. Defects are generated either through normal operation of the plant, working on repairs or inspections, installing defective parts, or through breakdowns of other equipment. The defects then stay in the equipment until they are identified or cause a breakdown. If not identified through inspections, a defect will eventually cause a piece of equipment to breakdown. Likewise, even after mechanics identify a defect, it must be repaired through scheduled maintenance, otherwise it will eventually cause the equipment to breakdown as well.

3.3.3 Learning Curves and Defect Sources

In this sub-sector defect generations are formulated. As the plant ages, some increase in plant defects occur due to wearing out of some equipment. Learning curves are also included to reflect the reduction in defect generation over plant life. There are many different types of learning within the plant. As plant operation hours accumulate, operators learn how to reduce component stress. Also, wear and tear on components declines due to break-in of equipment. As mechanics accumulate repair hours, they make fewer mistakes. Lastly, as personnel inspect more equipment, their inspection skills improve, so more defects are found at an earlier time.

Information and training impact the plant sector mainly through this sub-sector. As training hours increase, the learning curves improve, and as the utility invests more in information use, defect causes decrease.

3.3.4 Flows of Unscheduled Work Orders

This sub-sector accounts for repairs of all broken equipment. Once equipment breaks. its repair is simplified since it does not need to be inspected or scheduled. However, since worker productivity is lower when fixing broken equipment, equipment stays down longer. Also, since equipment could not be taken down at desirable time, such as during a periodic outage, each down piece of equipment has a greater impact on plant capacity.

The flows of this sub-sector include work order creation, engineer and manager review, material acquisition, partially functional equipment take down (a percentage of broken equipment), and work in progress. Once the broken equipment flows out of 'Work in Progress,' it is considered fully functional. However, new defects can be introduced during the repair process.

3.3.5 Flow of Scheduled Work Orders

This sub-sector controls PMP repairs. Discretionary inspections determine necessary repairs. The repairs are then scheduled, reviewed, and performed. Meanwhile, plans are created and materials are acquired for the job. The whole process is more efficient since the work is scheduled in advance. Additionally, workers introduce fewer new defects into the equipment, and the taken down equipment has reduced effect on plant capacity.

The goal of the utility is to eventually place all equipment in the PMP program. However, one of the balancing acts in the model is allocating workers and engineers between the unscheduled and scheduled maintenance programs. If managers allocate too many people to PMP then the broken equipment will not be repaired.

3.3.6 Maintenance Staff, Hiring Allocation and Overtime

This sub-sector is the heart of personnel allocation. The designs of Manager and Engineer allocations are similar. Only the functions of the personnel are different. Based on the budgeted allocation of resources, various fractions of maintenance workers either work on maintenance, perform inspections, train or plan work orders. Training will effect a reduction in time the mechanics spend on actual maintenance, but can provide a long term learning benefit. It is a good example of a delayed benefit. Other overhead type jobs are assumed to be an equal part of all the above jobs. If there is a shortage of workers, overtime results. As overtime increases, hiring increases. However, there are time delays and feedbacks that affect worker productivity. As overtime increases, worker productivity drops substantially. Alternately, if workers are under-utilized, their productivity will drop to fill the available time.

3.3.7 Mechanics time allocation

The division of mechanics' time between scheduled and unscheduled maintenance is assumed to occur automatically. The way the work allocator controls an increase in preventative maintenance is by increasing inspections up to the budget limit. The mechanics react to the incoming workload each week by assigning the required number of mechanics to the work. If there are too few mechanics, broken equipment receives priority. However, by increasing overtime, they will attempt to do all the required work.

The number of backlogged work-orders controls the capacity of the plant. This backlog represents the pieces of equipment that were not fixed at the end of the week. The pieces that are still broken reduce capacity.

3.3.8 Planners

There can be a delay in performing a work order because of time spent waiting for a correct plan for the job. This sub-sector controls the writing and reviewing of maintenance plans. If a plan for a job already exists in the plan library, the job is expedited. Otherwise, the worker must wait for a plan to be written and reviewed.

3.3.9 Mandatory and Discretionary Inspections

The budget allocator has the greatest direct impact on plant performance in this sub-sector. The budget allocator can control the number of discretionary inspections by assigning more mechanics. The Nuclear Regulatory Commission (NRC) can also effect more scheduled maintenance through mandatory inspections. As mandatory or discretionary inspections increase, the number of defects found increases, which will increase the number of scheduled work orders.

3.3.10 Materials Specifications

A mechanic needs repair parts to work a job. The budget allocator must allocate some money to maintaining a proper inventory. They can also invest money in new capital equipment or improve specifications of existing equipment and repair parts in this sub-sector. Improving part quality specifications reduces the number of defects per part. Buying all new equipment reduces the average age of equipment in the plant, which reduces operations defects in that equipment.

3.3.11 Engineer Allocation

The model allocates engineers similarly to Mechanics. They are hired and laid-off. They are allocated to maintenance, planning, and information. They also work overtime with lower productivity. The work allocator can allocate engineers among the different functions.

3.3.12 Management Allocation

Managers are allocated similarly to Engineers. They are also hired and laid-off. They are just more expensive and there are fewer. Their functions are finance, maintenance, and information.

3.3.13 Safety

The Safety sub-sector includes calculations of Man-Rem, Forced Outage Frequency and Estimated Core Melt Frequency. The Man-Rem estimate is determined by multiplying the amount of maintenance done by an average Rem per work order. The Forced Outage frequency is a probabilistic calculation based on the current average forced outage frequency for nuclear plants multiplied by a ratio of broken equipment and operator astuteness. Operator astuteness is determined primarily by training and information.

The Estimated Core Melt Frequency is determined by multiplying the current base core melt frequency {1/(20000 Reactor-Years)} by operator astuteness, broken equipment, and forced outage frequency factors. This calculation is not rigorous, but it provides a consistent simplified effect on overall core safety.

3.4 Financial Resources Sector

The Financial Sector includes all aspects of utility monetary operations. It includes internal finance balance sheets, the Public Utility Commission, the Stock Market, Bond Rating institutions, Economic effects, Perceived Financial Safety of Nuclear Plant, Budgeting and Allocation of resources Capital Investment, and Debt. The main causal loop, of the utility's equity, is shown in Figure 3.3.

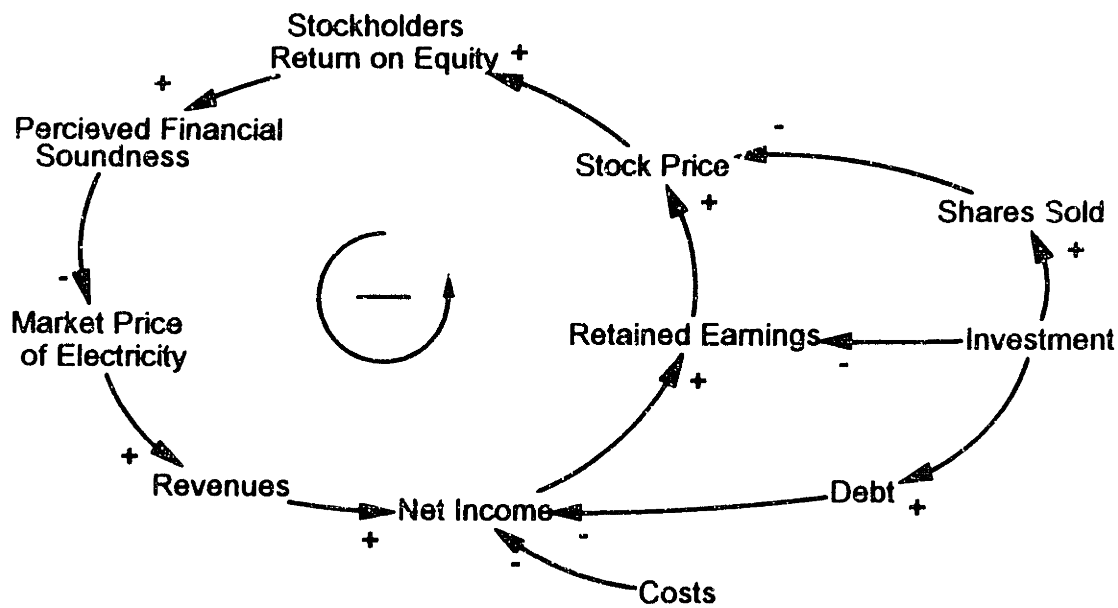


Figure 3.3: Causal Loop Diagram
Financial Sector, Equity Loop

3.4.1 Internal Finance

Cash Flows and the overall Balance Sheet are determined in this sub-sector. Costs are summed each week and subtracted off revenues to determine the gross margin. Investment, Property Taxes and then income taxes are subtracted. The remaining, net income minus dividends are forwarded to retained earning. An Asset, Liability, and Retained Earnings comparison is then made.

3.4.2 Public Utility Commission

The Public Utility Commission is influenced by customer satisfaction, utility performance, interest groups, and political ideas to determine a perceived prudence of the utility. This prudence translates into an allowed return on equity and an allowed rate base. Once the allowed return on equity is determined, it is translated into a cash value and compared with the utility's requested return.

If there is competition, this price represents only an allowed price. The price the utility must actually charge is competitor's price, which can be multiplied by a small increase based on proven reliable service. Additionally, PUC can change from benevolent to evil (in the eyes of the utility) based on political changes. The prudence will drop, causing the rate base to drop and the utility must make changes in its budget

3.4.3 Budgeting and Allocation

Here, the budget allocator has the most influence. Utility operations are controlled through allocation of dollars. The allocator can decide to spend more money on inspections, capital equipment, information, personnel, goodwill or lobbying.

3.4.4 Equity

The stock market is represented by a Capital Asset Pricing Model. The risk of investing in the utility is compared to Treasury Bills and the Dow Jones index. This results in a cost of capital, which is the required return on equity by an investor. This cost of capital is compared to the present value of estimated future cash flows of dividends to estimate a stock price. Combined with random variations and economic effects, this estimated stock price is converted into daily stock price.

Comparing book value of the utility with daily stock price determines if the utility can raise equity. If it can it sells shares to raise equity maintaining a 40% ratio, with debt contributing the remaining 60%.

3.4.5 Bond Rating Institutions

Bond Raters constantly monitor the financial position of utilities to determine their ability to repay long-term notes. The bond rating is on 1-12 scale from Default to AAA+.

3.4.6 Economic and Random Effects

This optional sub-sector inserts recessions, interest rate hikes, inflation and random effects onto the utility. It is usually off with inflation set to zero to facilitate interpretation of the model.

3.4.7 Perceived Financial Safety

This sub-sector represents an investor's perceived risk of losing investment due to a major accident at the nuclear plant. This risk influences the total risk of investing in the utility and affects the bond rating. It is determined by monitoring operations, SALP scores and forced outage frequency. Risks due to the PUC and economy are determined in the stock sector.

3.4.8 Capital Investment and Debt

The utility manages cash shortfalls and capital investments by financing 60% through long term debt. Since so much debt is incorporated during construction of the plant, approximately 70% of costs go to debt payments in the model. If a utility consistently overspends, it will enter a death spiral of debt.

Chapter 4

4.0 Information Sector

System dynamics is a modeling tool for simulating many types of different systems. Modeling the flows of information and their effects on the plant is a task easily handled in system dynamics. For the purpose of this thesis, it will be important to represent the plant's processing of information, and the associated costs and benefits of information use. Chapter 1 discussed how this information exchange can be used to better plant performance and decrease accident precursors. Hopefully, by showing this effect and others, this addition to the utility model will provide a tool to give greater insight into the use and costs of information exchange within a nuclear power plant. This chapter presents the components and boundaries of the system to be modeled, followed by the causal relationships, and lastly, the Ithink® system dynamics representation of the information system.

4.1 System Boundaries

The information sector concentrates upon the information exchange aspects of the nuclear industry. Maintenance operations of the plant, social/political interactions, and financial interactions are not within the boundaries of the information sector. A few variables from those activities may effect performance, delays, and decisions within the information sector, but they are external variables. In turn, the information sector supplies inputs for the model that can effect performance, safety ratings and financial costs.

The information sector is bounded by the information flows within the nuclear industry. This boundary will include information about experience, plant problems (in-plant and outside), and NRC regulations. Processing the information within the utility is included within this boundary. Boundaries were chosen so that a reasonable representation of the information flows could be obtained. There is a tremendous amount of available information in use today, and a complete, specific representation of all the flows would be unnecessary for the scope of this thesis. The information sector will incorporate enough information for effective results, and represent programs that a utility uses to process it.

Figure 4.1 shows a diagram of the components and functions of the information sector. There are five main components of the information sector, each of which contains Ithink® sub-sectors. 'Other Plants' includes sub-sectors that produce the unusual event occurrences and the associated problems that are reported. These problems are identified at the plants and are sent to 'Other Organizations,' who process the information into reports for the utility to study. These reports then go through the utility's processing, 'Use of Information' to correct potential problems within the plant. A fourth component interacts with the NRC during regulation development and implementation. Finally, 'Connections to Plant' couples the information sector with the utility model. This r includes variables from the plant and a few sub-sectors, such as the information learning curve, that are needed to couple the information sector to the utility model.

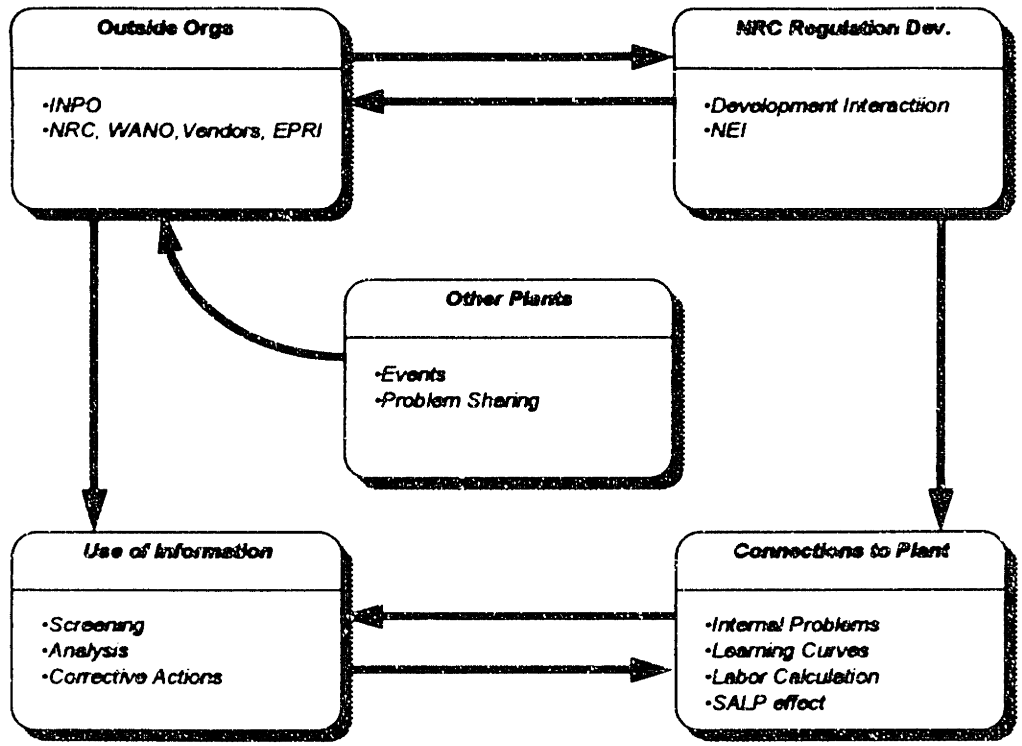


Figure 4.1: Major Components of Information Sector

The sub-sectors designed to process information are based on ideas obtained during conversations and correspondence with engineers at various utilities. The time delays and other constants were also obtained from this correspondence. The majority of these time delays and fractions are usually utility specific, but using the ones in this model provides a good representation of the processes.

There is very little direct feedback within the information sector. In the nuclear industry, information reports are produced for all unusual events and most significant operating experiences. It is a utility's decision to use the information the way they desire. Things such as political and social pressure may effect a utility's decision on how to use the information, but the use of it is straightforward and relatively standardized. It is essentially a process by which the reports are screened, analyzed and used to determine corrective actions. Until these actions are taken, no visible effect will be seen on the plant. These actions then work to better safety and improve plant performance. The controlling factor on information is the amount of manpower that the plant is willing to devote to using information. Manpower effects the time delays and effectiveness of corrective action implementation in the information sector. Currently, in the utility model, the manpower decision is left to the user, as would be a utility manager's decision. It is not a calculated model decision based on work to be done, social pressure, or other factors.

4.2 Causal Relationships

There is little direct feedback within the information sector. What are the relationships within the plant that effect information usage and effectiveness? Figure 4.2 presents the basic causal loop of how information usage can effect plant operations.

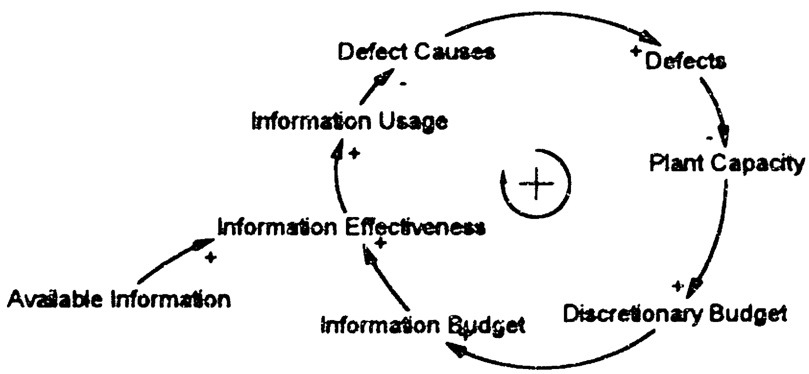


Figure 4.2: Causal Loop Diagram
Information Usage - No Competing Effects

It is a positive loop than can improve plant capacity by reducing defects (which cause breakdowns in plant equipment). Defects are diminished because their causes are reduced in the plant by taking corrective actions in the information sector. The main limitation on this positive loop is the amount of available information for use. If the information sector operated in an environment separate from all others in the plant, this causal loop would lead one to believe that the discretionary budget should be allocated totally to information use. However, this is not the case as information usage competes with other plant operations for funding.

The effectiveness of information usage in the model is driven mainly by the number of engineers and managers allocated to performing the information work. Another key use of professional staff in the plant is job review and approval in the maintenance sector. The number of people on the professional staff is budget limited, so the number allocated either to information or maintenance is an important model variable. Figure 4.3 shows the causal relationship of this situation.

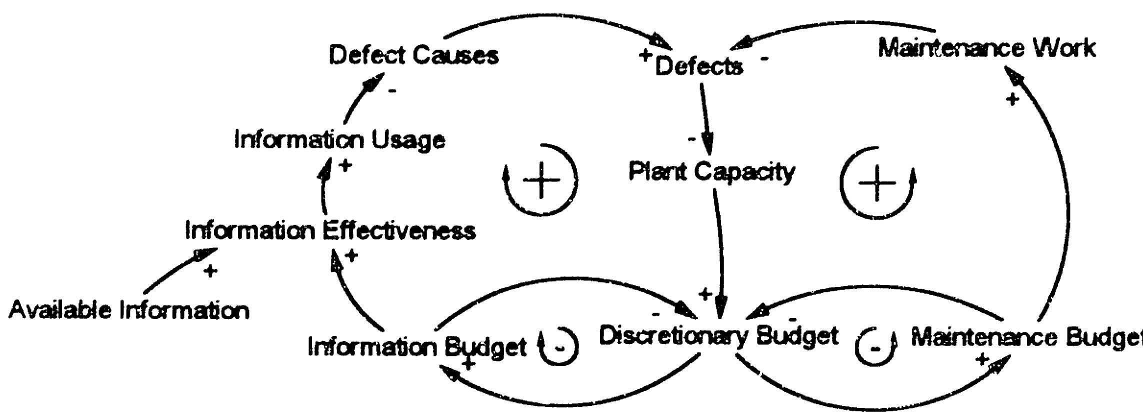


Figure 4.3: Causal Loop Diagram
Information Usage - Competition with Maintenance

Added to the previous causal loop is another positive loop, which shows the effect on capacity of performing maintenance work. This 'dual-positive loop' of Figure 4.3 is a common system dynamics situation in which two positive loops are interconnected and limited by a few variables. In this case the allocation of the budget between maintenance and information personnel is the variable that controls and limits these loops. The important difference between the two loops is that information use reduces the causes of defects and maintenance work fixes defects. There is an interplay between these two functions in the plant. Choosing the right amounts in the budget can create an optimal situation of fixing defects from operations and reducing their causes from information usage.

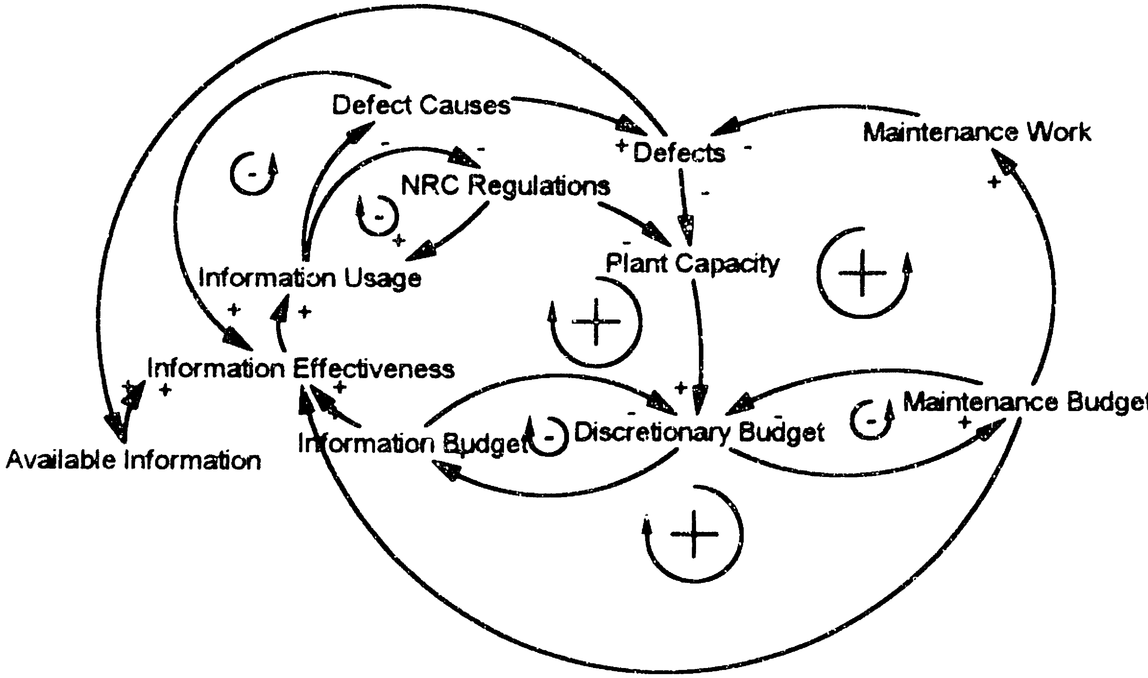


Figure 4.4: Causal Loop Diagram
More Information Effects

Other things affect the use of information within the plant. These are shown in Figure 4.4. Information use has a limited effect on defect causes. Information becomes less effective as more information is used in limiting the causes of defects. This is because the outside information can only identify some of the major defect causes. Also, information is also repetitive and redundant. The causal diagram also shows information from plant defects added to the available information for analysis. This increases the effectiveness of reducing defect causes, because there is more plant specific information. Additionally, the causal diagram depicts a simple representation of the information sector's involvement in regulations. It is possible to have the information staff work to get rid of NRC regulations under development in the model. If they are effective in this process of reducing the number of regulations put on the books, unnecessary maintenance work can be reduced. This can positively effect capacity, because less equipment is taken down during the unnecessary work.

4.3 Computer Representation

The causality and processes within the information sector need to be transferred to mathematics in order to simulate the ideas and see their effects on the model. Ithink® provides the tool to complete this modeling task. This mathematical modeling will enhance the relationships and information flows discussed.

The information sector is divided into 5 components, each of which can contain various sub-sectors. These sections of the information sector and their corresponding sub-sectors will be discussed in the following order:

- Other Plants - Industry Events
- Outside Organizations - Industry Problem Reporting, INPO
- Use of Information - Report Screening, In-Plant Problem Screening, Evaluation, Corrective Actions
- NRC Regulation - NRC Regulation Development
- Connections to Plant - Info Labor Calc, Info Learning Curve, Info SALP Effect

Each sub-sector discussion will include an Ithink® graphical representation, tables containing listings of variables and their units, initial stock values (SI), equations for flows (F), converter equations (C), and values for the constants (V). Initial values were chosen for the stocks so that the information sector could begin in equilibrium. Stock equations follow a standard formula, so it is not necessary to repeat it every time a stock appears in a sub-sector. This equation is:

$$stock(t) = stock(t - dt) + (inflow - outflow) * dt \qquad (3.1)$$

where stock(t) is the value of the stock at time t

and in/outflow are the incoming and outgoing flows to the stock.

In the graphical diagrams, external variables appear outside of the sub-sector under discussion. Appendix A contains the Ithink® equation listings in the same sub-sector order as this chapter. Appendix B contains an alphabetical glossary that describes all the variables in the information sector. In the variable discussion, the variables appear in italics,

4.3.1 Other Plants

Event precursor information is made available from events that occur at other nuclear plants. Previously, the model did not include a sub-sector to produce these events that regularly occur throughout the industry. It is these events that can produce information about problems in the industry. These problems come from various sources, such as operations, training, equipment, and maintenance. A sub-sector was built to perform this process.

4.3.1.1 Industry Events

Events will be classified by the NRC event classification levels. These are: unusual events, site alerts and site emergencies. In addition to those, there is an exogenous major event, which is defined as an event as threatening as TMI. The Ithink® representation of this sub-sector is shown in Figure 4.5

4.3.1.1.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
Event Processing (sub-model)	events	event pool reset	1. unusual event 2. site alerts 3. site emergencies	events/week

Table 4.1: Stocks and Flows - Industry Events

The *Event Processing* stock is actually a sub-model in this sub-sector. It is shown in Appendix C, as its detail is not important.

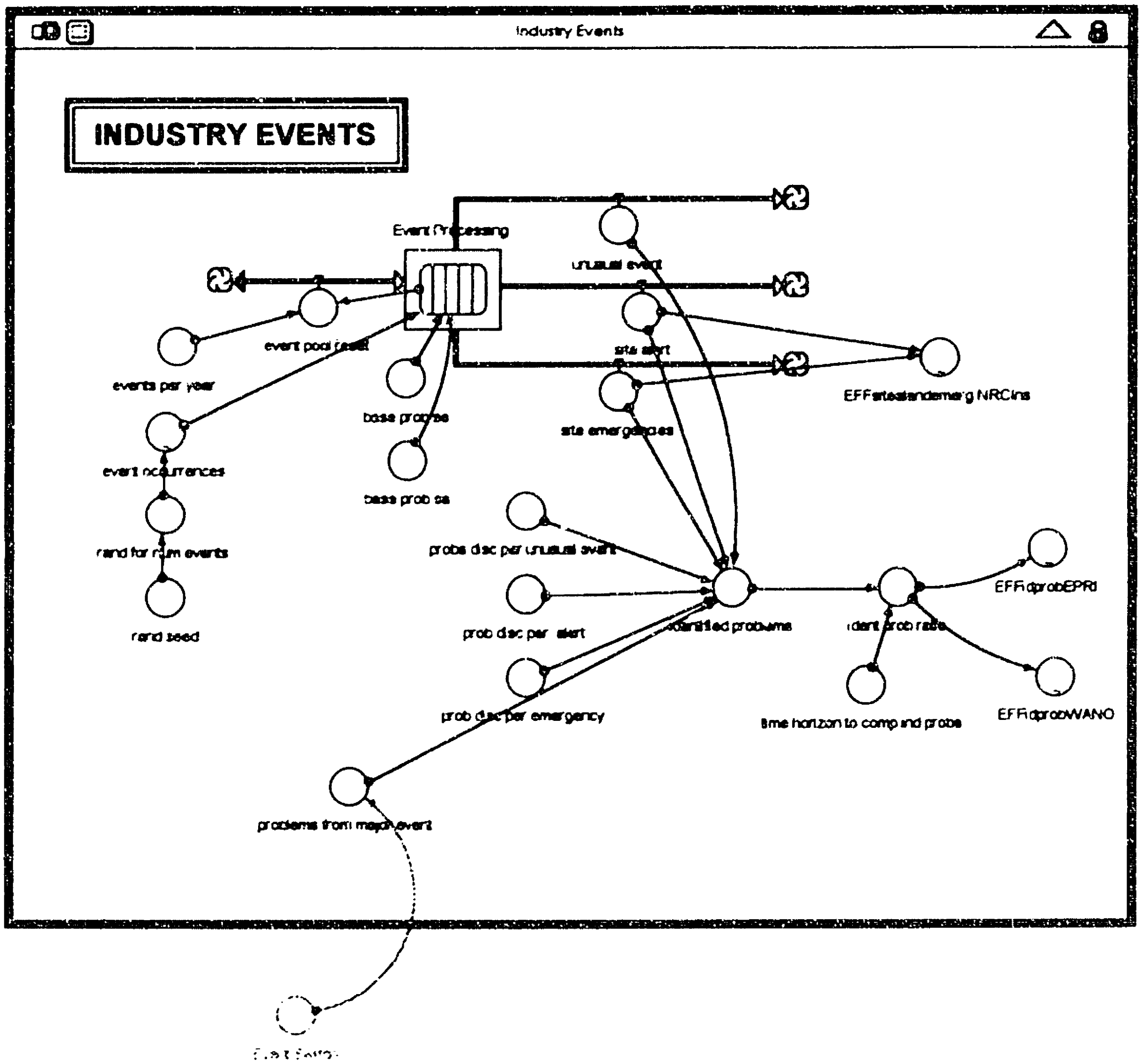


Figure 4.5: Ithink® Diagram
Industry Events

It will determine, based on various probabilities for event occurrences, the number and type of events every week. Instead of modeling an average incoming information, this sub-model detail provides variations in information amounts. For instance, if a high number of site alerts occur in a single week, a higher than normal amount of information is made available in reports to plants. The utility would then either have to incur extra overtime costs to process the additional information or have longer time delays in information processing because of the higher information staff workloads.

The important flows with this sub-sector are based on the calculations within the *Event Processing* sub-model. These flows are the outside occurrences that will produce the information from the discovery of new problems within the plants. Flows through *unusual event, site alert, or site emergency* are interpreted as occurrences of these events. The other flow in this sub-sector resets the sub-model for the number of possible events within a year.

4.3.1.1.1.1 Stock Initial Values and Flow Equations

F *event_pool_reset = PULSE(events_per_year,1,52)-PULSE(Event_Pool,52,52)*

F *site_alert = site_alert' (from sub-model)*

F *site_emergencies = site_emergencies' (from sub-model)*

F *unusual_event = unusual_event' (from sub-model)*

4.3.1.1.1.2 Converters

Converter	Units	Inputs
rand for num events	dimensionless	rand seed
identified problems	problems/week	1. unusual event 2. probs disc per unusual event 3. site alert 4. probs disc per alert 5. site emergencies 6. probs disc per emergency 7. probs from major event
ident prob ratio	problems/week	1. identified problems 2. time horizon to comp ind probs
probs from major event	problems/week	1. event switch
event occurrences	events/week	rand for num events
EFF sitealandemerg NRCIns	dimensionless	1. site alert 2. site emergencies
EFFidprobEPRI	dimensionless	ident prob ratio
EFFidprobWANO	dimensionless	ident prob ratio

Table 4.2: Converters - Industry Events

Identified problems calculates the number problems identified because of event occurrences. It is based on the number and type of events that occurred, and is the number of problems that become identified at the plants and sent to the various organizations for analysis and reporting. A problem can be thought of as pages of issues identified at the plants. Ident prob ratio is the ratio of current problems identified to those remembered over the time horizon.

The 'EFF' converters are also of interest in this sub-sector. The first of these, EFF sitealandemerg NRCIns, causes the NRC to increase inspections if there is large number of site alerts in a week or a site emergency. If the identified problem ratio increases, the other two 'EFF' converters increase the amount of research performed and number of reports generated at EPRI and WANO, respectively.

4.3.1.1.1.2.1 Converter Equations

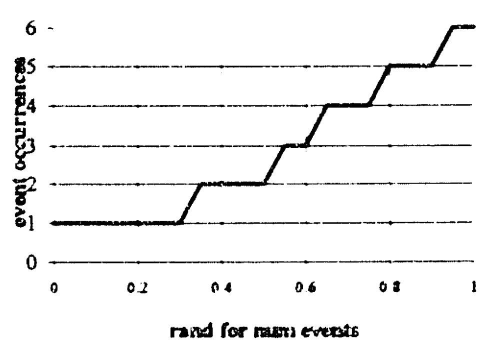
C *rand for num events = RANDOM(0,1,rand seed +100)*

C *identified problems = unusual event*probs disc per unusual event + site alert*prob disc per alert + site emergencies*prob disc per emergency + problems from major event*

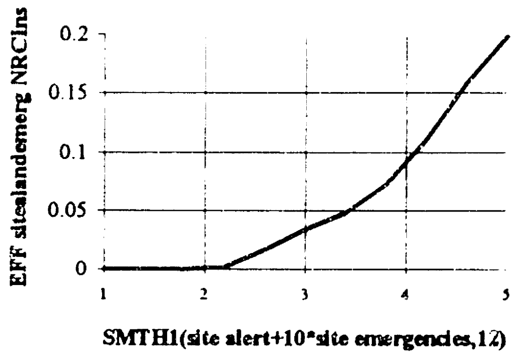
C *ident prob ratio = SMTH1(identified problems, 2,1)/SMTH1(identified problems, time horizon to comp ind problems, 10)*

C *problems from major event = IF (TIME=156) AND Event_Switch=1 THEN 1000 ELSE 0*

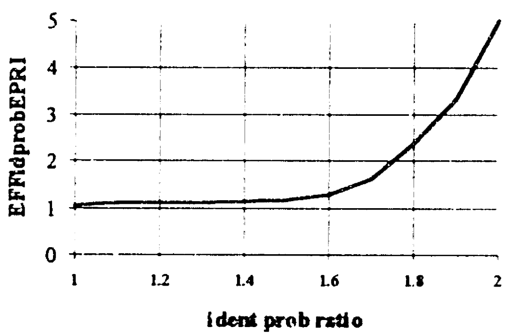
C *event occurrences = GRAPH(rand num for events)*



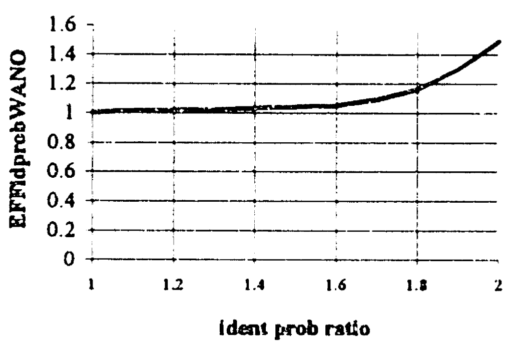
C *EFF sitealandemerg NRCIns = GRAPH(SMTH1(site alert+10*site emergencies, 12,1)*



C *EFFidprobEPRI = GRAPH(ident prob ratio)*



C *EFFidprobWANO = GRAPH(ident prob ratio)*



4.3.1.1.1.3 Constants

Constant	Units
base prob sa	site alerts/event occurence*100
base prob se	site emergencies/event occurence*100
events per year	events
probs disc per unusual event	problems/event
probs disc per alert	problems/event
probs disc per emergency	problems/event
rand seed	unitless
time horizon to comp ind probs	weeks

Table 4.3: Constants - Industry Events

Base prob sa and *base prob se* are the probabilities that an event occurrence is a site alert or site emergency (NRC data, Beckjord). *Event Processing* uses these probabilities to check each occurrence to determine what type it is. The '*probs disc*' variables set the number of problems discovered for each event type. As the event level worsens, more problems are discovered. The number of problems discovered is scaled exponentially. The *time horizon to comp ind probs* is the amount of time people in the industry remember the number of past problems that have occurred.

4.3.1.1.1.3.1 Constant Values

- *base prob sa = 10*
- *base prob se = 0.125*
- *events per year = 140*
- *probs disc per unusual event = 1*
- *probs disc per alert = 10*
- *probs disc per emergency = 100*
- *rand seed = 4000*
- *time horizaon to comp ind probs = 12*

4.3.1.1.1.4 External Variables

External Variable	Source Sub-Sector
event switch	Model Parameters (in utility model)

Table 4.4: External Variables - Industry Events

If a major event similar to TMI, occurs at another nuclear utility, a tremendous amount of information comes into the information sector.

4.3.2 Outside Organizations

After the problems are identified at the plants, they are sent to various national organizations for review. These organizations process the information into reports and notifications that the utilities use in their information processing systems. Two sub-sectors are included in this component of the information sector. The first sub-sector, problem reporting, distributes problems to the organizations and includes simple representations for a few of them. The other sub-sector is a model of INPO's report processing program for their SEE-IN network.

4.3.2.1 Industry Problem Reporting

One of the purposes of this sub-sector is to send appropriate fractions of the information to the organizations. Not all problems are reported to every organization. Some, such as vendors, only make use of some of the problem. It was not necessary to explicitly model every organization, so this sub-sector includes a few stocks and flows to represent the time delays in reports coming from national organizations other than INPO. The Ithink® representation of this sub-sector appears in Figure 4.6.

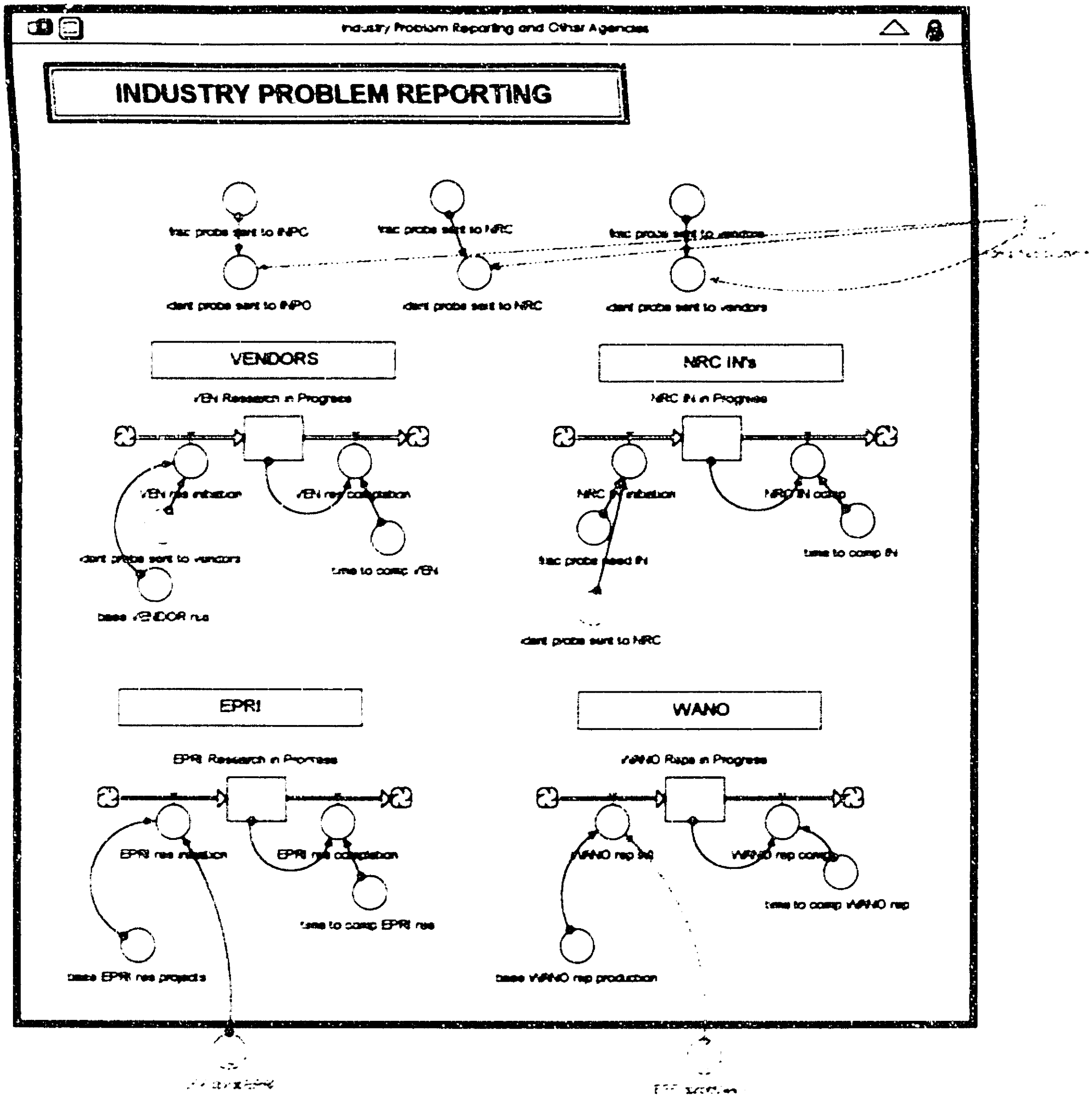


Figure 4.6: Ithink® Diagram
Industry Problem Reporting

Stock	Units	Inflow	Outflow	Units
EPRI Research in Progress	reports	EPRI res initiation	EPRI res completion	reports/week
NRC IN in Progress	reports	NRC IN initiation	NRC IN comp	reports/week
VEN Research in Progress	reports	VEN res initiation	VEN res completion	reports/week
WANO Reps in Progress	reports	WANO rep init	WANO rep comp	reports/week

Table 4.5: Stocks and Flows - Industry Reporting

4.3.2.1.1 Stocks and Flows

The stocks and flows in the sub-sector are used to represent the initiation of problem analyses and research projects within various national and international organizations. These are: EPRI, NRC, utility vendors, and WANO. Each of the sets of stocks and flows represent a time delay in the production of reports made available to the nuclear utilities. These stocks are initially set to zero, as it only takes a few weeks for them to reach equilibrium.

4.3.2.1.1.1 Stock Initial Values and Flow Equations

SI *EPRI Research in Progress = 0*

SI *NRC IN in Progress = 0*

SI *VEN Research in Progress = 0*

SI *WANO Reps in Progress = 0*

F *EPRI res initiation = base EPRI res projects*EFFidprobEPRI*

F *EPRI res completion = EPRI Research in Progress/time to comp EPRI res*

F *NRC IN initiation = frac probs need IN*ident probs sent to NRC*

F *NRC IN comp = NRC IN in Progress/time to comp IN*

F *VEN res initiation = base VENDOR res + ident probs sent to vendors*

F *VEN res completion = VEN Research in Progress/time to comp VEN*

F *WANO rep init = base WANO rep production*EFFidprobWANO*

F *WANO rep comp = WANO Reps in Progress/time to comp WANO rep*

4.3.2.1.2 Coverters

Converter	Units	Inputs
ident probs sent to INPO	problems/week	1. identified problems 2. frac probs sent to INPO
ident probs sent to NRC	problems/week	1. identified problems 2. frac probs sent to NRC
ident probs sent to vendors	problems/week	1. identified problems 2. frac probs sent to vendors

Table 4.6: Converters - Industry Reporting

These three converters calculate the number of problems sent to different organizations. INPO and the NRC review most of the problems that are identified at the plants. Vendors only review the problems when issues are specific to their own products or research.

4.3.2.1.2.1 Converter Equations

C *ident probs sent to INPO = frac probs sent to INPO*identified problems*

C *ident probs sent to NRC = frac probs sent to NRC*identified problems*

C *ident probs sent to vendors = frac probs sent to vendors*identified problems*

4.3.2.1.3 Constants

Constant	Units
frac probs sent to INPO	dimensionless
frac probs sent to NRC	dimensionless
frac probs sent to vendors	reports/problem
frac probs need IN	reports/problem
base VENDOR res	reports
base EPRI res projects	reports
base WANO rep production	reports

Table 4.7: Constants - Industry Reporting

The first three fractions are used in the converter calculations that determine the number of reports being sent to each type of organization. The *frac probs need IN* is used to calculate the number of problems sent to the NRC that initiate the writing of Information Notifications (IN). The last three variables are the equilibrium rates that vendors, EPRI, and WANO produce reports. These are reports on research, such as a new method to handle pump maintenance, or reports coming in from international operation experiences through WANO.

4.3.2.1.3.1 Constant Values

V *frac probs sent to INPO = 1*

V *frac probs sent to NRC = 1*

V *frac probs sent to vendors = 0.10*

V *frac probs need IN = 0.50*

V *base VENDOR res = 1*

V *base EPRI res projects = 1*

V *base WANO rep production = 2*

4.3.2.1.4 External Variables

External Variable	Source Sub-Sector
identified problems	Industry Events
EFFidprobEPRI	Industry Events
EFFidprobWANO	Industry Events

Table 4.8: External Variables - Industry Reporting

All three of these come from the sub-sector that produces industry events. *Identified problems* is the number of problems recognized at the plants because of event occurrences. If there is a significant increase in the number of events occurring throughout the industry, the other two variables increase the number of reports being produced at EPRI and WANO..

4.3.2.2 INPO

This sub-sector is an explicit representation of how INPO processes problems through its SEE-IN network. Again, INPO is modeled separately because it is the most effective and influential information exchange organization in the industry. The model structure is a simple representation of the problem reviews and report productions (Rees 1994, p.127). Three different types of reports are produced in this sub-sector. They are:

- SEN - Significant Event Notification. Alerts plants as promptly as possible that a significant event has occurred. Further information may be followed in a SER.

- SER - Significant Event Report. Provides a brief description of a significant event or problem and comments on why it was significant.

- SOER - Significant Operating Experience Report. When INPO recommendations result from evaluations of the identified problems, they are incorporated into a SOER. A SOER is prepared for problems that require the most focused utility attention.
  (Boston Edison 1992, p. 6)

Of importance, are the time delays for report production, and the fractions that determine the number of different reports produced for each problem identified. The Ithink® representation of this sub-sector is shown in Figure 4.7.

4.3.2.2.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
Probs Waiting for Screen by INPO	problems	problems reported to INPO	INPO probs screened	problems/ week
INPO Prob Analysis in Progress	problems	INPO prob analysis init	INPO prob analysis comp	problems/ week
SER Writing in Progress	reports	SER initiation	SER reports	reports/ week
Recs Waiting for Further Investigation	reccommendations	new recs to inform	1. field invest planned 2. quick SOER responses	1. field invest/ week 2. report/ week
INPO Field Invests in Progress	field investigations	field invest planned	INPO rec field invest completed	field invest/ week

Table 4.9: Stocks and Flows - INPO

Probs Waiting for Screen by INPO are the problems reported to INPO that have not been screened by an INPO engineer. If they are screened, and determined to have a possible safety impact on the plants, a SEN will immediately be written to inform the utilities of a problem. At this time, all significant problems initiate the writing of SER's, represented by *SER Writing in Progress*. The next stock, *INPO Prob Analysis in Progress*, represents a more intensive review of significant problems to determine specific recommendations. Two stocks are related to further processing of these recommendations. The first, *Recs Waiting for Further Investigation*, represents recommendations waiting to be investigated further with field investigations and recommendations that are being written

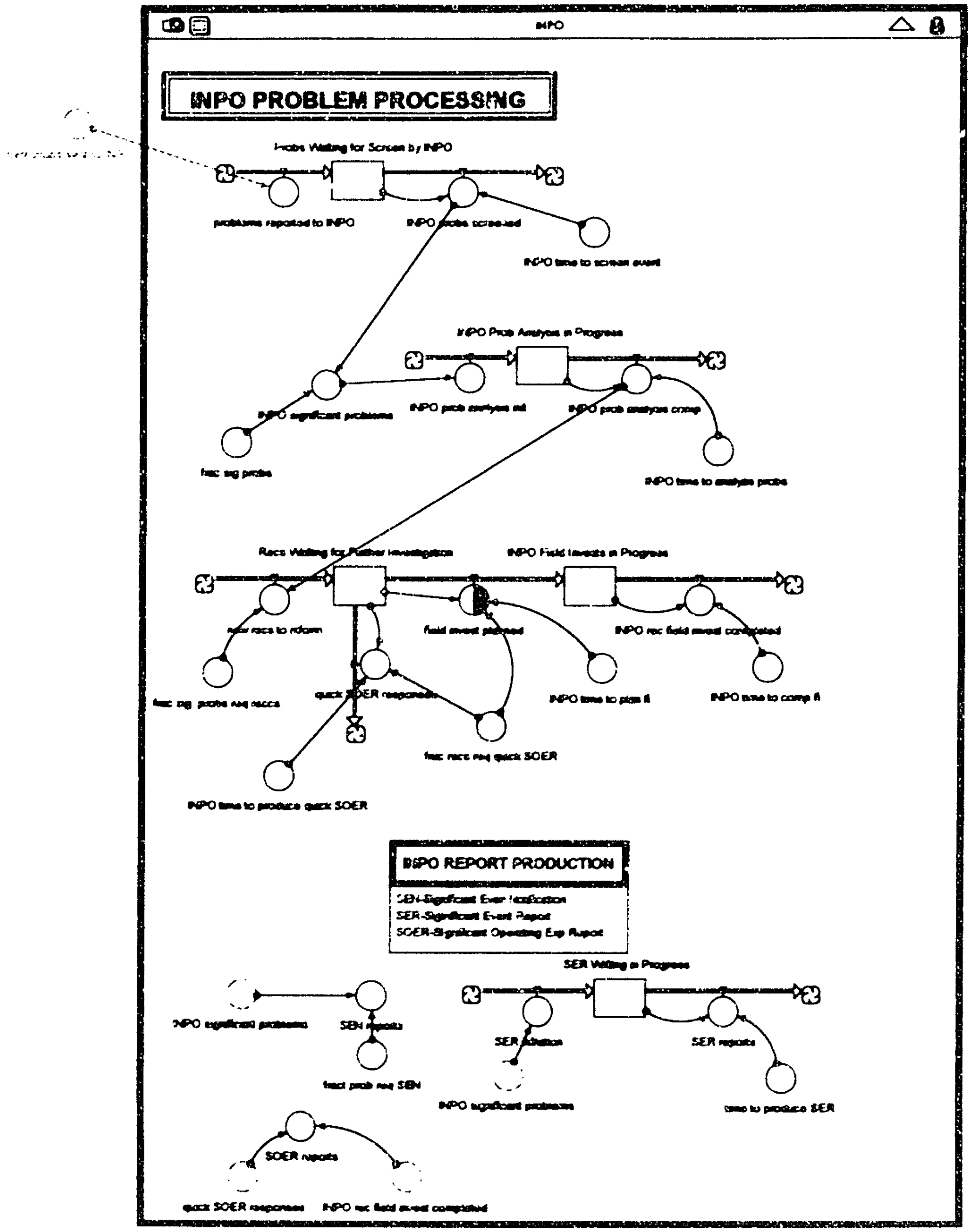


Figure 4.7: Ithink® Diagram
INPO Problem Processing Sub-sector

into 'quick' SOER responses. The other stock, *INPO Field Invests in Progress*, is a stock of INPO field investigations that are initiated by these recommendations.

4.3.2.2.1.1 **Stock Initial Values and Flow Equations**

SI *Probs Waiting for Screen by INPO = 10*

SI *INPO Prob Analysis in Progress = 15*

SI *SER Writing in Progress = 20*

SI *Recs Waiting for Further Investigation = 5*

SI *INPO Field Invests in Progress = 3*

F *problems reported to INPO = ident probs sent to INPO*

F *INPO probs screened = Probs Waiting for Screen by INPO/INPO time to screen event*

F *INPO prob analysis init = INPO significant problems*

F *INPO prob analysis comp = INPO Prob Analysis in Progress/INPO time to analyze probs*

F *SER initiation = INPO significant problems*

F *SER reports = SER Writing in Progress/time to produce SER*

F *new recs to inform = INPO prob analysis comp*frac sig probs req reccs*

F *field invest planned = (1- frac recs req quick SOER)* Recs Waiting for Further Investigation/INPO time to plan fi*

F *quick SOER responses = Recs Waiting for Further Investigation*frac recs req quick SOER/INPO time to produce quick SOER*

F *INPO rec field invest completed = INPO Field Invests in Progress/INPO time to comp fi*

4.3.2.2.2 Converters

Converter	Units	Inputs
INPO significant problems	problems/week	1. INPO probs screened 2. frac sig probs
SEN reports	reports/week	1. INPO significant problems 2. fract prob req SEN
SOER reports	reports/week	1. INPO rec field invest completed 2. quick SOER responses

Table 4.10: Converters - INPO

INPO significant problems is the number of problems that INPO determines significant during the screening process. Problems are considered significant if they contain issues that can influence safety and/or performance in other plants throughout the industry. A fraction of the significant problems are considered important enough that INPO immediately sends out a SEN report to identify it to the industry. The *SEN reports* converter represents this relation.

4.3.2.2.2.1 Converter Equations

C *INPO significant problems = INPO probs screened*fract prob req SEN*

C *SEN reports = INPO significant problems* frac sig probs*

C *SOER reports = INPO rec field invest completed + quick SOER responses*

4.3.2.2.3 Constants

Constant	Units
fract prob req. SEN	reports/problem
frac recs req quick SOER	reports/rec
frac sig probs	dimensionless
frac sig probs req reccs	recc/problem
INPO time to analyze probs	week
INPO time to comp fi	week
INPO time to produce quick SOER	week
INPO time to screen event	week
INPO time to produce SER	week

Table 4.11: Constants - INPO

The fractional constants are used in converters for calculating either the number significant problems or reports produced for each problem. The time delays represent the time it takes an INPO engineer to screen, review, or analyze problems. It is assumed that INPO has enough staff, so there will be no delays coming from staffing shortages or work overloads.

4.3.2.2.3.1 Constant Values

- V *fract prob req. SEN = 0.20*
- V *frac recs req quick SOER = 0.60*
- V *frac sig probs = 0.80*
- V *frac sig probs req reccs = 0.50*
- V *INPO time to analyze probs = 2*
- V *INPO time to comp fi = 6*
- V *INPO time to produce quick SOER = 1*
- V *INPO time to screen event = 1*
- V *INPO time to produce SER = 2*

4.3.2.2.4 External Variables

External Variable	Source Sub-Sector
ident probs sent to INPO	Industry Reporting

Table 4.12: External Variables - INPO

This variable comes from the sub-sector that determines the of identified problems that are sent to INPO for analysis.

4.3.3 Use of Information

This component of the information sector represents the programs and processes that are implemented for using the information within the plant. These include processes to screen and analyze the information, and to determine corrective actions to take (Boston Edison 1992 & 1994). Creating these provided a simple representation of how a utility makes use of the information available to it. It is not an exact representation of how a specific utility is using the information, but it will depict the delays and manpower involved in processing information. Four sub-sectors are in this section: Report Screening, In-Plant Problem Screening, Evaluation, and Corrective Action Process.

Time delays in using information are adjusted by the availability of engineers and managers for information processing. The standard converter for time delays will be calculated as:

$$time\ delay = base\ time\ delay * unavailability\ ratio \qquad (3.2)$$

where base time delay is how long it takes, on average, for a staff member to do the job

and unavailability ratio is the ratio of work to be done in the information sector to available amount of work completion.

Using this formula for time delays gives feedback of understaffing or overstaffing the information sector. For example, if the information processing is understaffed, the unavailability ratio goes up, and the time delays in processing are increased. The modified time delays are converters, and their names begin with 'adj' to indicate that they are adjusted for engineer unavailability. In some cases the base time delay is one time step (dt). In actuality, the delay may be even less, but making time delays less than dt in Ithink® causes peculiar stock and flow behavior.

4.3.3.1 Report Screening

All reports coming into the utility, are quickly screened by an available information engineer. Screening is performed to determine whether the problems addressed in the reports are applicable to the plant or have been analyzed previously. SOER's are screened separately from the other reports because the information in them is usually of high importance to the utility, and needs to be screened as quickly as possible. The Ithink® representation of this sub-sector is shown in Figure 4.8.

4.3.3.1.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
SOERs Waiting for Screening	reports	Incoming SOERs	SOER Screened	reports/week
Reps Waiting for Screening	reports	Incoming Reps	1. reports screened 2. reps abandoned	reports/week

Table 4.13: Stocks and Flows - Report Screening

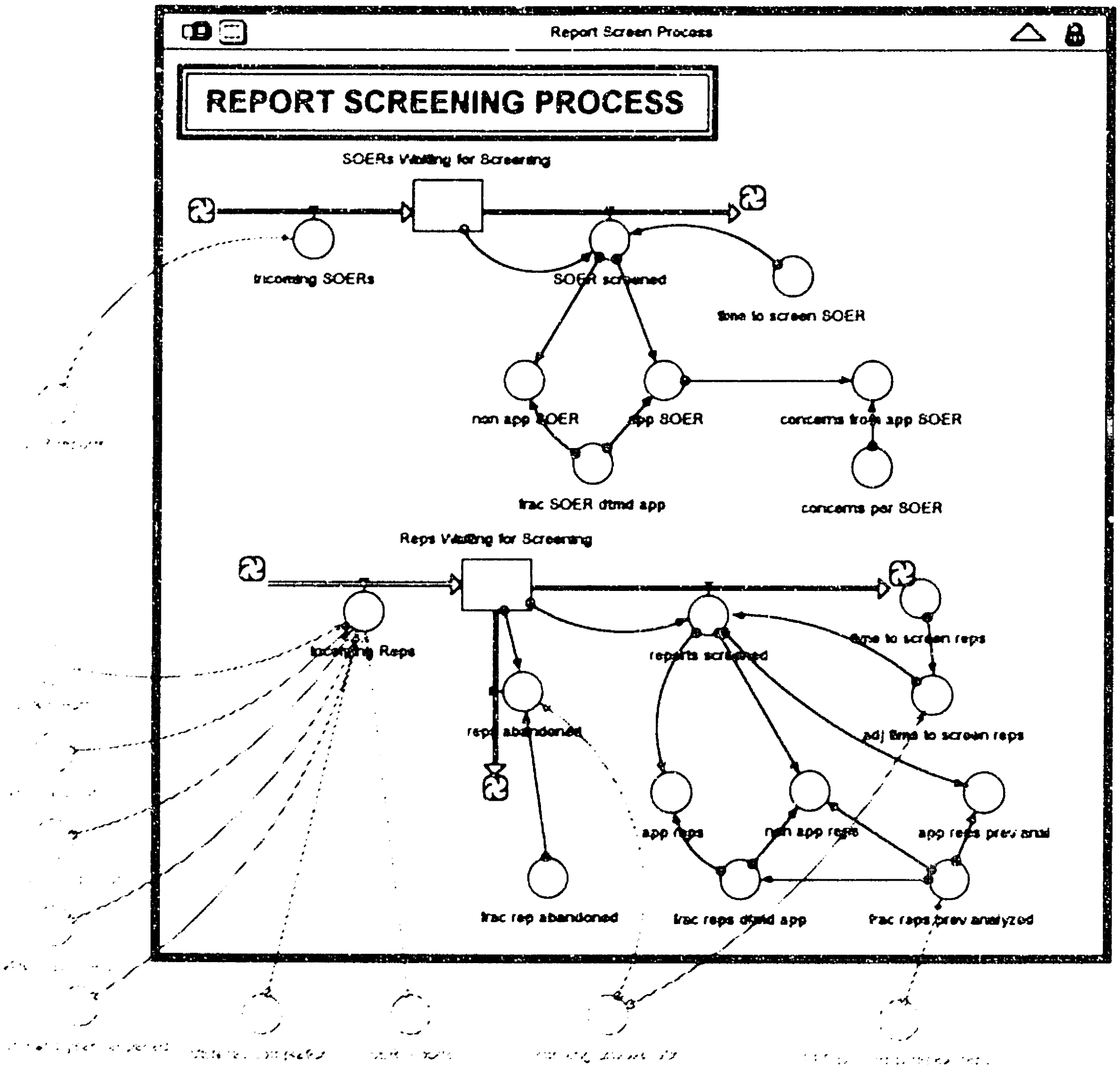


Figure 4.8: Ithink® Diagram
Report Screening Sub-sector

Both stocks in this sub-sector represent reports that are waiting to be screened by an engineer. These could be thought of as reports sitting on someone's desk waiting to be screened. The reps abandoned flow represents reports that are not screened because there are not enough engineers to handle all the information work. These reports go into a pool of reports that were not completely analyzed

4.3.3.1.1.1 Stock Initial Values and Flow Equations

SI *SOERs Waiting for Screening = 5*

SI *Reps Waiting for Screening = 70*

F *Incoming SOERs = SOER reports*

F *SOER Screened = SOERs Waiting for Screening/ time to screen SOER*

F *Incoming Reps = EPRI res completion + NRC IN comp + SEN reports + VEN res completion + WANO rep comp + SER reports +_ report analyses reopened*

F *reports screened = Reps Waiting for Screening/ adj time to screen reps*

F *reps abandoned = IF (info eng unavial ratio>4) THEN frac rep abandoned* Reps Waiting for Screening ELSE 0*

4.3.3.1.2 Converters

Converter	Units	Inputs
adj time to screen reps	weeks	1. time to screen reps 2. info eng unavail ratio
app reps	reports	1. reports screened 2. frac reps dtmd app
app reps prev anal	reports	1. reports screened 2. frac reps prev analyzed
app SOER	reports	1. SOER screened 2. frac SOER dtmd app
concerns from app SOER	reports	1. app SOER 2. concern per SOER
frac reps dtmd app	evals/report	frac reps prev analyzed
frac reps prev analyzed	evals/report	EFF DEF RED repeat reps
non app reps	reports	1. reports screened 2. frac reps prev analyzed 3. frac reps dtmd app
non app SOER	reports	1. SOER screeened 2. frac SOER dtmd app

Table 4.14: Converters - Report Screening

These converters are involved in calculating the applicability of reports during the engineers' screening. Reports can be determined applicable or non-applicable (frac reps dtmd app). For example, a report may be on a valve problem at a BWR, a specific problem not applicable to a PWR plant. In addition to this, it is possible that similar reports have also been reviewed at the plant before (frac reps prev analyzed). These previously reviewed reports will not be analyzed any further. Also, more reports are not analyzed because of repetition in the information reports. This is reflected in the converter, frac reps prev analyzed.

4.3.3.1.2.1 Converter Equations

C *adj time to screen reps = time to screen reps*infor eng unavial ratio*

C *app reps = reports screened*frac reps dtmd app*

C *app reps prev anal = report screened*frac reps prev analyzed*

C *app SOER = SOER screened*frac SOER dtmd app*

C *concerns from app SOER = app SOER*concerns per SOER*

C *frac reps dtmd app = 1-frac reps prev analyzed*

C *frac reps prev analyzed = 0.3*EFF DEF RED repeat reps*

C *non app reps = reports screened*(1-frac reps prev analyzed-frac reps dtmd app)*

C *non app SOER = SOER screened*(1-frac SOER dtmd app)*

4.3.3.1.3 Constants

Constant	Units
concerns per SOER	evals/report
frac rep abandoned	dimensionless
frac SOER dtmd app	dimensionless
time to screen reps	1
time to screen SOER	dt

4.15 Constants - Report Screening

Concerns per SOER is the number of problem evaluations that must be performed per SOER. This is the average number of recommendations that are brought up within applicable SOERs. *Frac rep abandoned* is the fraction of reports that are not screened because of engineer unavailability.

4.3.3.1.3.1 Constant Values

V *concerns per SOER* = 5

V *frac rep abandoned* = 0.40

V *frac SOER dtmd app* = 0.80

V *time to screen reps* = 1

V *time to screen SOER* = dt

4.3.3.1.4 External Variables

External Variable	Source Sub-Sector
EFF DEF RED repeat reps	Info Learning Curve
EPRI res completion	Problem Reporting
VEN res completion	Problem Reporting
NRC IN comp	Problem Reporting
WANO rep comp	Problem Reporting
SEN reports	INPO
SER reports	INPO
SOER reports	INPO
report analyses reopened	Info SALP effect
info eng unavail ratio	Info Labor Calc

Table 4.16: External Variables - Report Screening

EFF DEF RED repeat reps is based on the information learning curve. As learning from information increases, more reports contain information about problems previously analyzed. The next 7 external variables in Table 4.16 are the various reports produced in the industry. All of these are screened. Report analyses reopened are reports previously abandoned, because of manpower shortages, that are reopened for analysis.

4.3.3.2 In-Plant Problem Screening

In addition to studying outside information, the information sector provides the ability to study internal plant problems also. When defects are discovered, they are fixed within the maintenance sector of the plant. With the information sector, the plant studies what causes the defects, and takes corrective actions to prevent then from occurring again. There are two screenings in this process. Initially, the problems are screened by the head shift nuclear engineer (usually called the Nuclear Watch Engineer or NWE), and then screened by the technical group designated for reviewing in-plant problems. The NWE screening is included because some problems dictate the initiation of immediate corrective actions. This sub-sector is depicted in Figure 4.9.

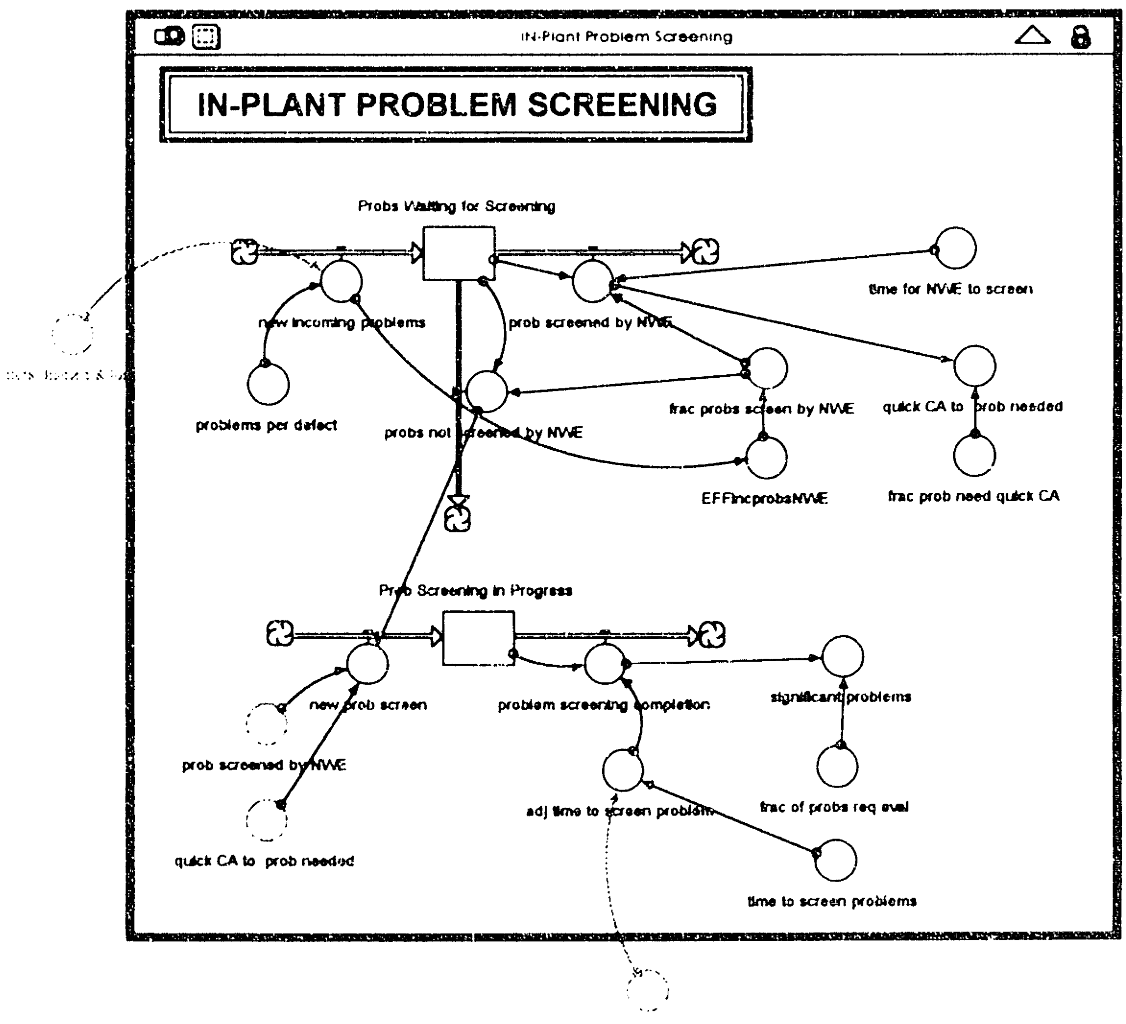


Figure 4.9: Ithink® Diagram
In-Plant Problem Screening

4.3.3.2.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
Probs Waiting for Screening	problems	new incoming problems	1. prob screened by NWE 2. probs not screened by NWE	problems/ week
Prob Screening in Progress	problems	new prob screen	problem screening completion	problems/ week

Table 4.17: Stocks and Flows - In-Plant Problem Screening

Probs Waiting for Screening is a stock of problems discovered from new defects in the plant. If the NWE is available, they are screened to see if corrective actions need to be taken immediately. All problems (except the ones that were sent for quick corrective actions) are then screened or re-screened by other information engineers to determine if they are significant to the plant.

4.3.3.2.1.1 Stock Initial Values and Flow Equations

SI *Probs Waiting for Screening = 0*

SI *Prob Screening in Progress = 30*

F *new incoming problems = IF dfcts discvrd & lost > 0 THEN dfcts discvrd & lost* problems per defect ELSE 0*

F *prob screened by NWE = Probs Waiting for Screening * frac probs screen by NWE/ time for NWE to screen*

F *probs not screened by NWE = Probs Waiting for Screening*(1- frac probs screen by NWE)*

F *new prob screen = probs not screened by NWE + prob screened by NWE - quick CT to prob needed*

F *problem screening completion = Prob Screening in Progress/ adj time to screen problem*

4.3.3.2.2 Converters

Converter	Units	Inputs
adj time to screen problem	weeks	1 time to screen problems 2 info eng unavail ratio
EFFincprobsNWE	dimesionless	new incoming problems
frac prob screen by NWE	dimensionless	EFF incprobsNWE
NWE	engineer	prob screened by NWE
quick CA to prob needed	CA/week	1 prob screened by NWE 2 frac prob need quick CA
significant problems	evals/week	1 problem screening completion 2 frac of probs req eval

Table 4.18: Converters - In-Plant Problem Screening

EFFincprobs NWE changes the fraction of problems that the NWE is able to screen. As the number of problems in the current week goes up in comparison to the number of past problems, the NWE is able to screen a smaller fraction of the new problems. This limits the amount of problem screening that the NWE can do. *Quick CA to prob needed* are problems that the NWE determines to need corrective actions quicker than normally. Significant problems are problems discovered through defects that are significant enough to warrant further evaluation in the information sector.

4.3.3.2.2.1 Converter Equations

C *adj time to screen problem = time to screen problems*info eng unavail ratio*

C *EFFincprobsNWE = SMTH1(new incoming problems,4,20)/new incoming problems*

C *frac prob screen by NWE = .25*EFF incprobsNWE*

C *quick CA to prob needed = prob screened by NWE *frac prob need quick CA*

C *significant problems = problem screening completion*frac of probs req eval*

4.3.3.2.3 Constants

Constant	Units
frac of probs req eval	eval/problem
frac prob need quick CA	CA/problem
problems per defect	problem/defect
time for NWE to screen	week
time to screen problems	week

Table 4.19: Constants - In-Plant Problem Screening

The first two fractions are used in converters that determine the number of problems that require further evaluation, and the number of problems that need quick corrective actions taken. Problems per defect is the number of problems reported from a certain number of defects. This is high because many defects combine before large problems are noticed.

4.3.3.2.3.1 Constant Values

C *frac of probs req eval = 0.75*

C *frac prob need quick CA = 0.25*

C *problems per defect = 1/50*

C *time for NWE to screen = dt*

C *time to screen problems = 2*

4.3.3.2.4 External Variables

External Variable	Source Sub-Sector
dfcts discvrd & lost	Defect Flows (in utility model)
info eng unavail ratio	Info Labor Calc

Table 4.20: External Variables - In-Plant Problem Screening

Dfcts discvrd & lost is the flow that represents the discovery of defects within the plant. Defects are discovered through both mandatory and discretionary inspections.

4.3.3.3 Evaluation

Once reports and in-plant problems are screened for applicability or redundancy, they are sent to engineers to be evaluated further. These evaluations consist of reviewing plant-specific design, procedures, practices, and operating history to identify weaknesses or vulnerabilities that could result in similar events at the plant. Before any further actions can be taken, the evaluations are then reviewed by managers for correctness. The Ithink® representation of this sub-sector is shown in Figure 4.10.

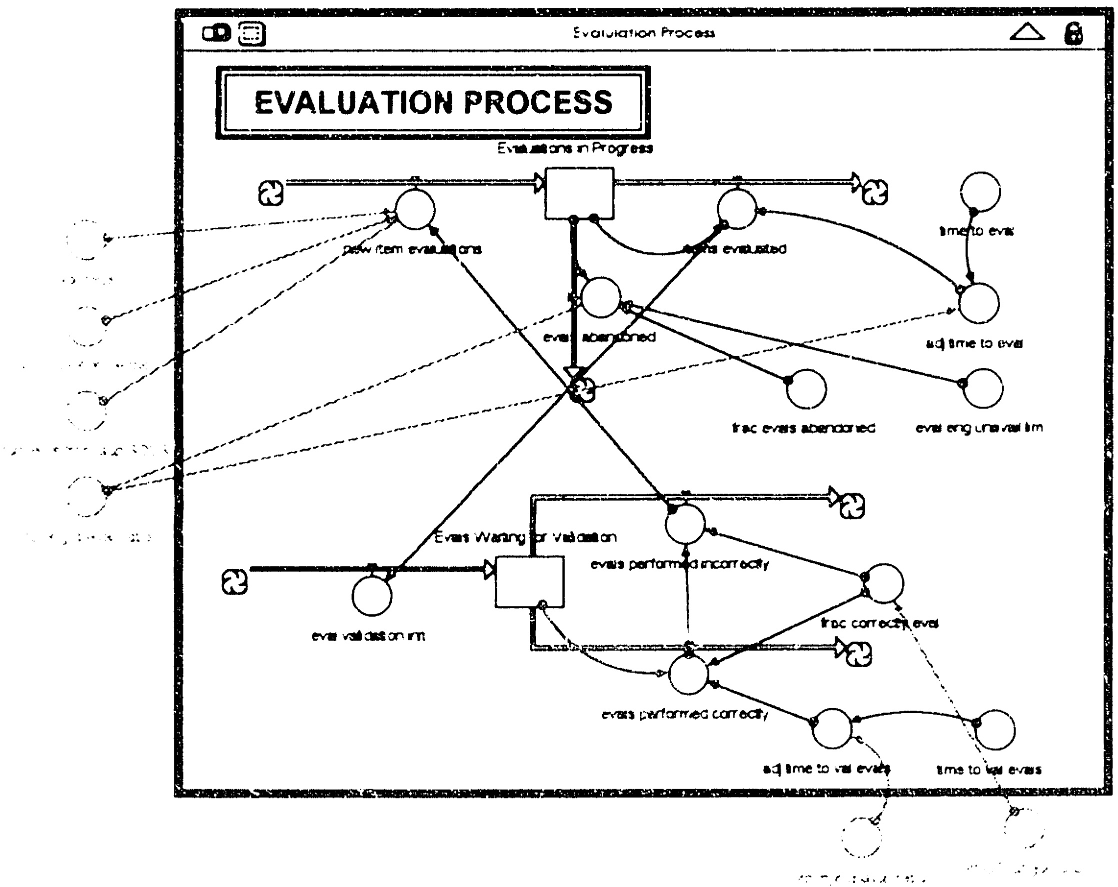


Figure 4.10: Ithink® Diagram
Evaluation

4.3.3.3.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
Evaluations in Progress	evals	new item evaluations	1. item evaluated 2. evals abandoned	evals/week
Evals Waiting for Validation	evals	eval validation init	1. evals performed correctly 2. evals performed incorrectly	evals/week

Table 4.21: Stocks and Flows - Evaluation

Two stocks exist in this sub-sector. The first, *Evaluations in Progress,* represents the number of evaluations that the engineers are performing. The other stock represents completed evaluations that are waiting to be validated by an information manager.

4.3.3.3.1.1 Stock Initial Values and Flow Equations

SI *Evaluations in Progress = 275*

SI *Evals Waiting for Validation = 45*

F *new item evaluations = app reps + concerns from app SOER + significant problems + evals performed incorrectly*

F *items evaluated = Evaluations in Progress/ adj time to eval*

F *evals abandoned = IF (info eng unavail ratio>eval eng unavail lim) THEN frac evals abandoned* Evaluations in Progress ELSE 0*

F *eval validation init = items evaluated*

F *evals performed correctly = frac correctly eval * Evals Waiting for Validation/ adj time to val evals*

F *evals performed incorrectly = evals performed correctly*((1-frac correctly eval)/frac correctly eval)*

4.3.3.3.2 Converters

Converter	Units	Inputs
adj time to eval	week	1. time to eval problems 2. info eng unavail ratio
adj time to val evals	week	1. time to val evals 2. info mgr unavail ratio
frac correctly eval	dimensionless	eff OT fatigue eng

Table 4.22: Converters - Evaluation

As with the other information processing sub-sectors, the time delays in evaluations are adjusted for engineer and manager unavailability. The fraction of evaluations that are performed correctly, *frac correctly eval*, is adjusted for fatigue of the engineers. If engineers are performing extraordinary amounts of ov rtime, errors in evaluations increase.

4.3.3.3.2.1 Converter Equations

C *adj time to eval = time to eval * info eng unavail ratio*

C *adj time to val evals = time to val evals * info mgr unavail ratio*

C *frac correctly eval = 0.85 * eff OT fatigue_eng*

4.3.3.3.3 Constants

Constant	Units
eval eng unavail lim	dimensionless
frac evals abandoned	dimensionless
time to eval	week
time to val eval	week

Table 4.23: Constants - Evaluation

The *eval eng unavail lim* is the highest value for *info eng unavail ratio* that is allowed until engineers begin to abandon evaluations because they are too busy. The *frac evals abandoned* is the fraction of total evaluations that are forgotten when this limit is reached.

4.3.3.3.3.1 Constant Values

V *eval eng unavail lim = 3*

V *frac evals abandoned = .10*

V *time to eval = 6*

V *time to val eval = 1*

4.3.3.3.4 External Variables

External Variable	Source Sub-Sector
app reps	Report Screening
concerns from app SOER	Report Screening
significant problems	In-Plant Problem Screening
eff OT fatigue eng	Engineer Allocation (in utility model)
info eng unavail ratio	Info Labor Calc
info mgr unavail ratio	Info Labor Calc

Table 4.24: External Variables - Evaluation

The first three variables in Table 4.24 are applicable reports and significant problems that need to be evaluated further to determine their impact on the utility. *Eff OT fatigue eng* effects the performance of engineers on evaluations.

4.3.3.4 Corrective Actions

Corrective actions are taken when evaluations determine that changes must be made in the plant to prevent the problems from surfacing. Three types of corrective actions are taken within the plant: procedures are written or revised, new training methods and procedures are created, and plant modifications are made. New and revised procedures can help to reduce defect causes because workers have more complete and less erroneous procedures available for maintenance work and operations. Enhancing worker training makes staff more knowledgeable and less error prone in the work they perform. Modifications increase plant specifications for materials and reduce defects in completing new scheduled work orders. Figure 4.11 shows the Ithink® diagram of this sub-sector.

This sub-sector has two major processes. In the first, a manager assigns an appropriate engineer to perform the corrective actions. The second process is the completion of the corrective action. This may include writing a procedure, creating and planning a modification, or reviewing and changing training procedures. These are performed by engineers, and reviewed for correctness by managers before they can effect the plant.

4.3.3.4.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
CA Waiting for Assignment	CA	new CA waiting	1. CA assignment 2. CA abandon	CA/week
Proc CA In Progress	CA	proc CA	proc CA completed	CA/week
Proc CA Waiting for Val	CA	proc CA completed	1. proc CA validated 2. proc CA incorrect	CA/week
Mod CA in Progress	CA	new mod CA	mod CA planned	CA/week
Train CA in Progress	CA	train CA	train CA completed	CA/week
Train CA Waiting for Val	CA	train CA completed	1. train CA validated 2. train CA incorrect	CA/week

Table 4.25 Stocks and Flows - Corrective Actions

CA Waiting for Assignment are corrective actions waiting to be assigned to an engineer. If the manager or engineers are overworked, the corrective actions are abandoned before they are implemented. *Proc CA, Mod CA, Train CA in Progress* represents engineers working on writing, planning, and implementing corrective actions. The effectiveness of procedure and training corrective actions is lessened if maintenance workers are overworked. *Proc CA and Train CA Waiting for Val* are corrective actions waiting for approval by a manager.

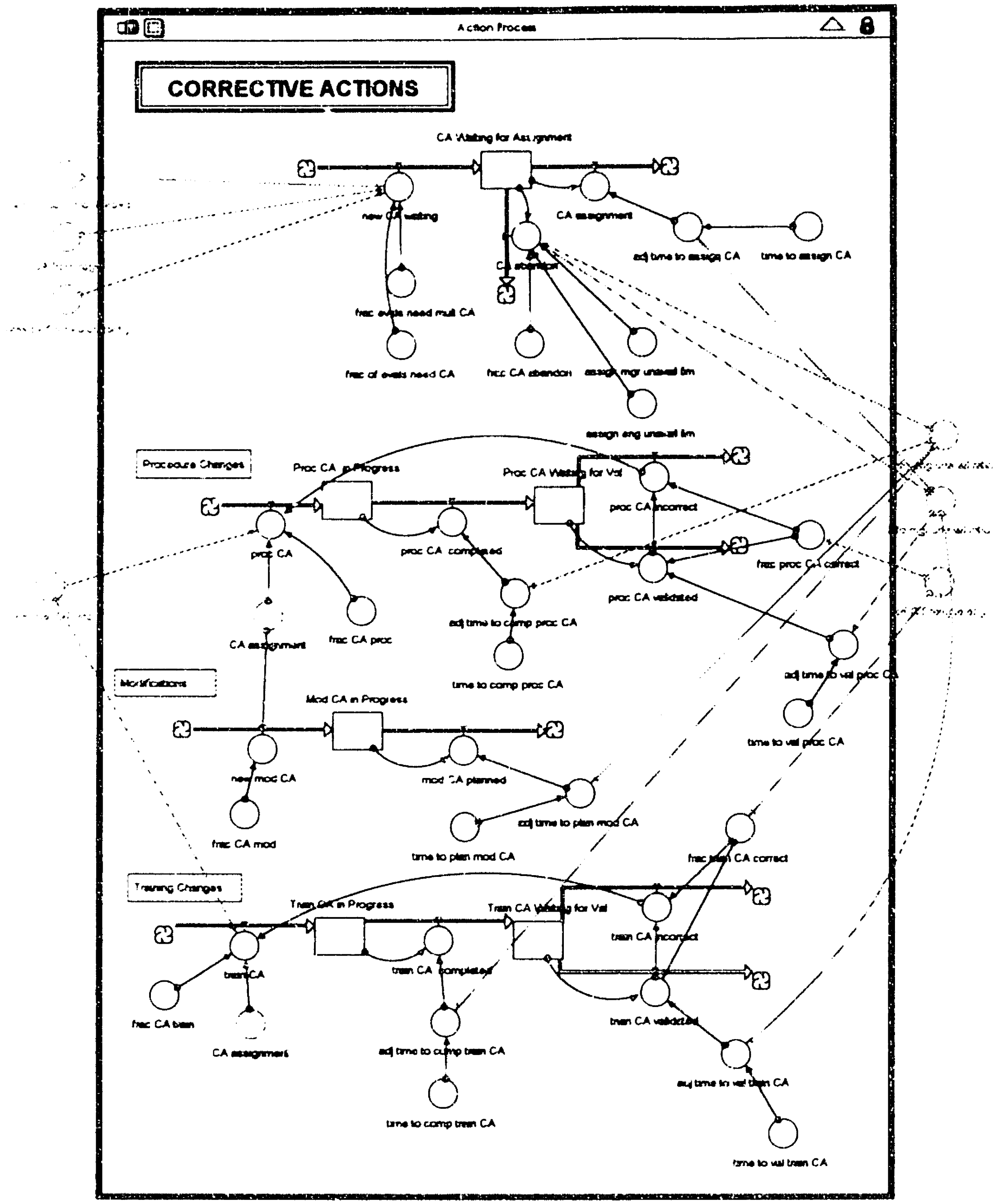


Figure 4.11: Ithink® Diagram
Corrective Action Process

4.3.3.4.1.1 **Stock Initial Values and Flow Equations**

SI	*CA Waiting for Assignment = 35*
SI	*Proc CA In Progress = 200*
SI	*Proc CA Waiting for Val = 25*
SI	*Mod CA in Progress = 80*
SI	*Train CA in Progress = 200*
SI	*Train CA Waiting for Val = 15*
F	*new CA waiting = evals performed correctly*frac of evals need CA*(1+frac evals need mult CA) + quick CA to prob needed + CA from regs*
F	*CA assignment = CA Waiting for Assignment/adj time to assign CA*
F	*CA abandon = IF (info mgr unavail ratio > assign mgr unavail lim) OR (info eng unavail ratio > assign eng unavail lim) THEN CA Waiting for Assignment*frac CA abandon ELSE 0*
F	*proc CA = (CA assignment*frac CA proc + proc CA incorrect)*EFF mainOT info*
F	*proc CA completed = Proc CA in Progress/ adj time to comp proc CA*
F	*proc CA validated = frac proc CA correct*Proc CA Waiting for Val/ adj time to val proc CA*
F	*proc CA incorrect = proc CA validated*((1-frac proc CA correct)/frac proc CA correct)*
F	*train CA = (CA assignment*frac CA train + train CA incorrect)*EFFmainOTinfo*
F	*train CA completed = Train CA in Progress/adj time to comp train CA*
F	*train CA validated = frac train CA corret*Train CA Waiting for Val/ adj time to val train CA*
F	*train CA incorrect = train CA validated*((1-frac train CA correct)/frac train CA correct)*
F	*new mod CA = CA assignment*frac CA mod*
F	*mod CA planned = Mod CA in Progress/ adj time to plan mod CA*

4.3.3.4.2 Converters

Converter	Units	Inputs
adj time to assign CA	week	1. time to assign CA 2. info mgr unavail ratio
adj time to comp proc CA	week	1. time to comp proc CA 2. info eng unavail ratio
adj time to comp train CA	week	1. time to comp train CA 2. info eng unavail ratio
adj time to plan mod CA	week	1. time to plan mod CA 2. info eng unavail ratio
adj time to val proc CA	week	1. time to val proc CA 2. info mgr unavail ratio
adj time to val train CA	week	1. time to val train CA 2. info mgr unavail ratio
frac proc CA correct	dimensionless	eff OT fatigue eng
frac train CA correct	dimensionless	eff OT fatigure eng

Table 4.26: Converters - Corrective Actions

Corrective actions are a very labor intensive part of the information sector, as they are extremely time consuming to complete. All of the time delays are adjusted for the availability of engineers and managers. The fraction of corrective actions performed correctly, *frac proc CA correct and frac train CA correct*, become lower if engineers are working large amounts of overtime.

4.3.3.4.2.1 Converter Equations

C *adj time to assign CA = time to assign CA*info mgr unavail ratio*

C *adj time to comp proc CA = time to comp proc CA*info eng unavail ratio*

C *adj time to comp train CA = time to comp train CA*info eng unavail ratio*

C *adj time to plan mod CA = time to plan mod CA*info eng unavail ratio*

C *adj time to val proc CA = time to val proc CA*info mgr unavail ratio*

C *adj time to val train CA = time to val train CA*info mgr unavail ratio*

C *frac proc CA correct = 0.90*eff OT fatigue eng*

C *frac train CA correct = 0.90*eff OT fatigure eng*

4.3.3.4.3 Constants

Constant	Units
assign eng unavail lim	week
assign mgr unavail lim	week
frac CA abandon	dimensionless
frac CA mod	dimentionless
frac CA proc	dimensionless
frac CA train	dimensionles
frac evals need mult CA	dimensionless
frac evals need CA	CA/eval
time to assign CA	week
time to comp proc CA	week
time to comp train CA	week
time to plan mod CA	week
time to val proc CA	week
time to val train CA	week

Table 4.27: Constants - Corrective Actions

Assign eng unavail lim and *assign mgr unavial lim* are the highest values for the engineer and manager unavailability ratios allowed until corrective actions are abandoned. *Frac CA mod, proc, and train* are the fractions of corrective actions that are procedure, training or modification actions. *Frac evals need mult CA* is the fraction of evaluations that need multiple corrective actions for completion. The time constants are how long it takes for an engineer or manager to complete an action if enough are available to perform all the work.

4.3.3.4.3.1 Constant Values

V *assign eng unavail lim = 3*

V *assign mgr unavail lim = 3*

V *frac CA abandon = 0.20*

V *frac CA mod = 0.20*

V *frac CA proc = 0.60*

V *frac CA train = 0.20*

V *frac evals need mult CA = 0.20*

V *frac evals need CA =0.75*

V *time to assign CA = 1*

V *time to comp proc CA = 10*

V *time to comp train CA = 26*

V *time to plan mod CA = 12*

V *time to val proc CA = 1*

V *time to val train CA = 2*

4.3.3.3.4 External Variables

External Variable	Source Sub-Sector
evals performed correctly	Evaluation
CA from regs	NRC Regulation Dev.
quick CA to problem needed	In-Plant Problem Screening
eff OT fatigue eng	Engineer Allocation (in utility model)
EFF mainOT infor	Mechanics (in utility model)
info eng unavail ratio	Info Labor Calc
info mgr unavail ratio	Info Labor Calc

Table 4.28: External Variables - Corrective Actions

The first three external variables are the sources of information for the corrective actions. These come from previous report evaluations, problems to be corrected in regulations, and the quick corrective actions found from in-plant problem screening. The overtime variables effect the implementation of corrective actions by making implementation less effective when workers are performing overtime.

4.3.4 NRC Regulations

Nuclear plants also include information groups to oversee the NRC regulation process. These groups perform technical reviews of regulations under development at the NRC, interact with NEI for this development, and perform extensive evaluations of a regulation's impacts on the plant.

4.3.4.1 NRC Regulation Development

This sub-sector provides some of a plant's interactions with the NRC for new regulation development. The regulations are first given to managers to assign technical reviews for regulations under development. Sometimes, concerns about a regulation's impact are brought to surface at the utility. This concerns are brought to the NRC through the NEI, who helps work with the utility to modify or get rid of the regulations. Once regulations are put on the books at the NRC, the plant will again review them and follow through on inspections, material specification changes, and corrective actions they outline. This sub-sector diagram appears in Figure 4.12.

4.3.4.1.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
Reg Reviews Waiting for Asssign	regs	new regs to review	reg reviews assigned	regs/week
Regulations Under Technical Review	regs	tech review of regs init	1. reg des aband 2. reg reviews completed	regs/week
NEI Abandon Effort in Progress	regs	NEI effort to aband reg	regs des aband	regs/weel
Reg Eval in Progress	regs	new regs to implement	new reg evals completed	regs/week

Table 4.29: Stocks and Flows - NRC Regulation Dev.

The unit of 'regs' is thousands of pages of regulations. *Reg Reviews Waiting for Assign* is a stock of regulations that are waiting to be assigned by an engineer to a technical group for review. These reviews are *Regulations Under Technical Review*. *NEI Abandon Effort in Progress* is the number of regulations in development that the NEI is working to remove from development. *Reg Eval in Progress* are regulation evaluations that determine what corrective actions or material specifications to make in the plant.

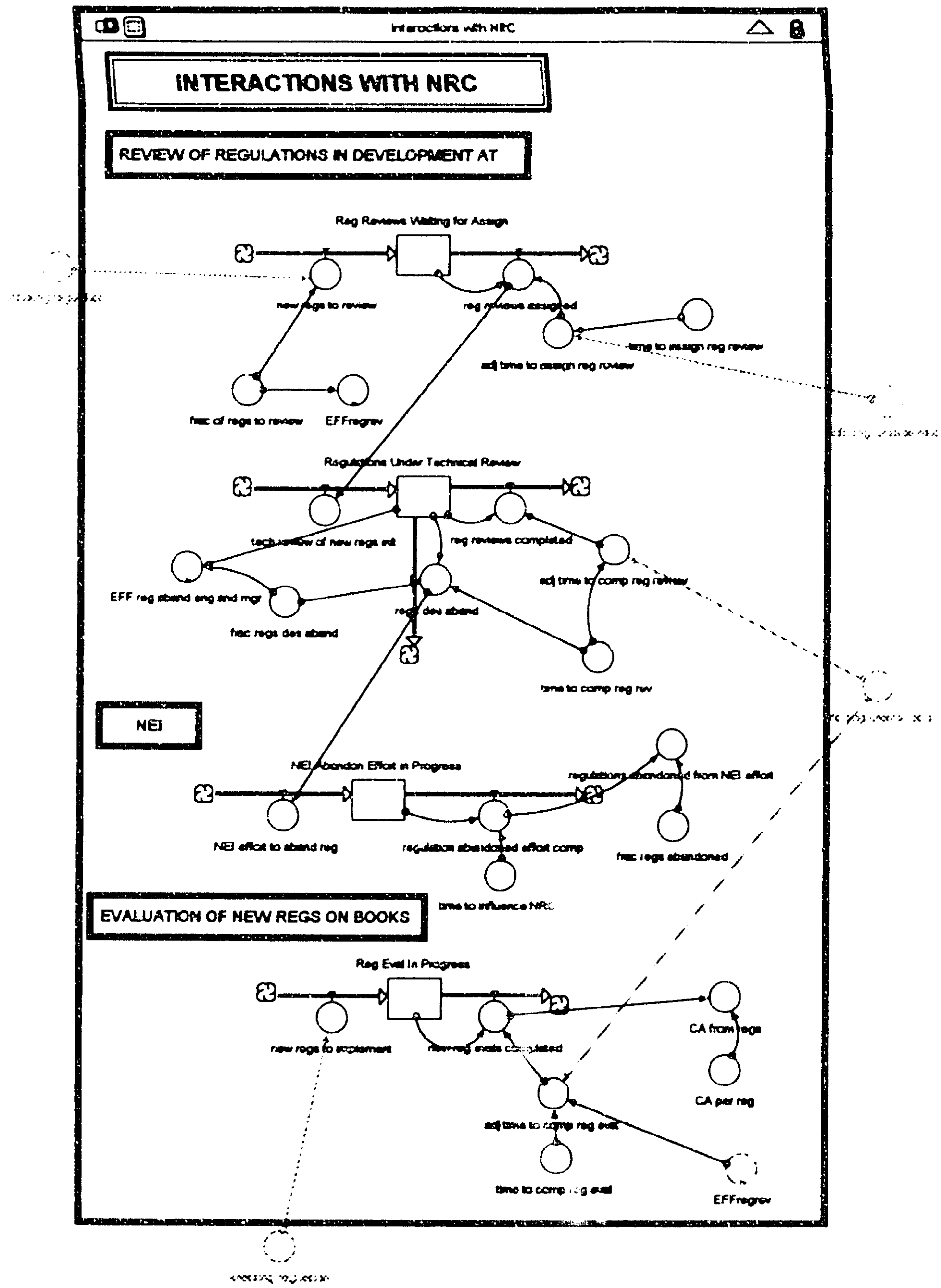


Figure 4.12: Ithink® Diagram
NRC Regulation Development

4.3.4.1.1.1 Stock Initial Values and Flow Equations

SI *Reg Reviews Waiting for Asssign = 0*

SI *Regulations Under Technical Review = .2*

SI *NEI Abandon Effort in Progress = 0*

SI *Reg Eval in Progress =0*

F *new regs to review = frac of regs to review*initiating regulation*

F *reg reviews assigned = Reg Reviews Waiting for Asssign/adj time to assign reg review*

F *tech review of regs init = reg reviews assigned*

F *reg des aband = frac regs des aband*Regulations Under Technical Review/(time to comp reg rev/4)*

F *reg reviews completed = Regulations Under Technical Review/adj time to comp reg rec*

F *NEI effort to aband reg = regs des aband*

F *regulations abandoned effort comp = NEI Abandon Effort in Progress/time to influence NRC*

F *new regs to implement = enacting regulation*

F *new reg evals completed = Reg Eval in Progress/ adj time to comp reg eval*

4.3.4.1.2 Converters

Converter	Units	Inputs
adj time to assign reg review	week	1. time to reg review 2. info mgr unavail ratio
adj time to comp reg eval	week	1. time to comp reg eval 2. info eng unavail ratio
adj time to comp reg review	week	1. time to comp reg review 2. info eng unavail ratio
CA from regs	CA	1. new reg evals completed 2. CA per reg
regulations abandoned from NEI effort	regs	1. frac regs abandoned 2. regulation abandoned effort comp
EFFregrev	dimensionless	frac of regs to review
EFF reg aband eng and man	dimensionless	1. Regulations Under Technical Review 2. Time 3. frac regs des aband

Table 4.30: Converters - NRC Regulation Dev.

Because this regulation review program is in the information sector, the time delays will again be adjusted for staff availability. *CA from regs* is the number of corrective actions that are needed because of information learned in the regulation evaluation. Regulations abandoned from NEI effort is the number of regulations that are abandoned. Only a fraction of the effort leads to this. Not all NEI effort is effective in changing a regulation. If the plant lowers its frac of regs to review, *EFFregrev* increases the time delay for regulation implementation.. This occurs because the engineers do not have the knowledge of the regulation that would have been obtained in the regulation review process. *EFF reg aband eng and man*, is an effect that reflects the use of engineers and managers within the plant when it tries to prevent regulations from getting on the books at the NRC. It is a multiplier on the total number of professional staff available for work.

4.3.4.1.2.1 Converter Equations

C *adj time to assign reg review = time to reg review*info mgr unavail ratio*

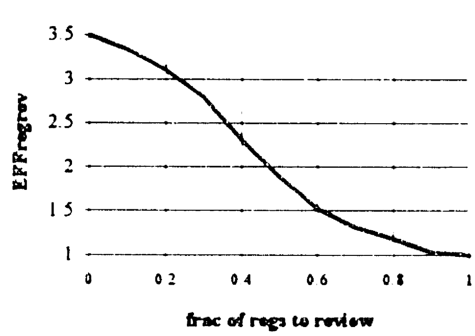
C *adj time to comp reg review = time to comp reg review*info eng unavail ratio*

C *adj time to comp reg eval =EFF regrev*time to comp reg eval*info eng unavail ratio*

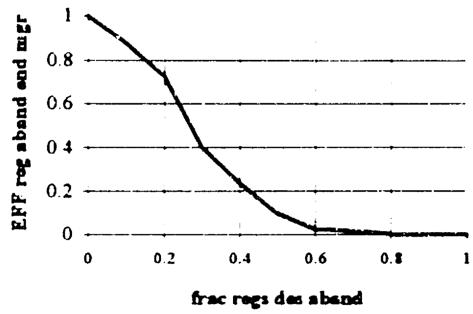
C *CA from regs = new reg evals completed*CA per reg*

C *regulations abandoned from NEI effort = frac regs abandoned*regulation abandoned effort comp*

C *EFFregrev = GRAPH(frac of regs to review)*



C *EFF reg aband eng and man = GRAPH(IF Regulations Under Technical Review> .15 AND TIME > 104 THEN frac regs des aband ELSE 0*



4.3.4.1.3 Constants

Constant	Units
frac regs to review	dimensionless
frac regs des aband	dimensionless
frac reg abandoned	dimensionless
CA per reg	CA/regs
time to assign review	week
time to comp reg rev	week
time to influence NRC	week

Table 4.31: Constants - NRC Regulation Development

Frac regs to review and *frac regs des aband* are constants that can be set to different levels for studying feedback of abandoning regulations. *Frac reg abandoned* is the efficiency of the NEI's regulation abandonment effort.

4.3.4.1.3.1 Constant Values

V *frac regs to review = 1.00*

V *frac regs des aband = 0.0*

V *frac reg abandoned = 1.0*

V *CA per reg = 25*

V *time to assign review = 1*

V *time to reg eval = 6*

V   *time to comp reg rev = 12*

V   *time to influence NRC = 12*

4.3.4.1.4 External Variables

External Variable	Source Sub-Sector
info eng unavail ratio	Info Labor Calc
info mgr unavail ratio	Info Labor Calc
initiating regulation	NRC (in utility model)
enacting regulation	NRC (in utility model)

Table 4.32: External Variables - NRC Regulation Dev.

Initiating regulation and *enacting regulation* are from the NRC sub-sector. *Initiating regulation* is a flow that depicts regulations beginning development, and *enacting regulation* is the flow to regulations on the books.

4.3.5 Connections to Plant

In addition to various variables that come directly from the utility model sub-sectors, a few additional sub-sectors needed to be added to the information sector before it could be connected to the utility. These sub-sectors provide the labor calculation for the information engineers and managers, the learning curve for information and a direct effect of information usage on SALP scores.

4.3.5.1 Information Labor Calculation

This elementary sub-sector calculates the information engineer and manager unavailability ratios that are used to adjust the numerous time delays in the information processing of the model. The stocks of information being screened, evaluated, and undergoing corrective actions are brought into this sub-sector as external variables to calculate the amount of work to be done in the information sector. Figure 4.13 shows this sub-sector.

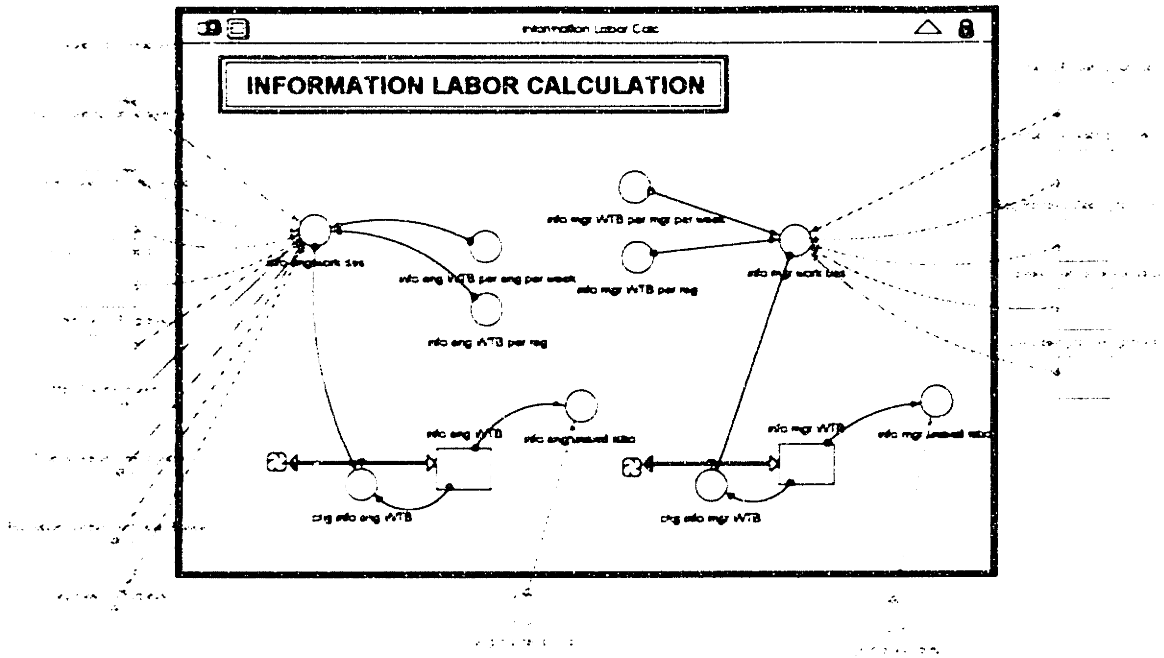


Figure 4.13: Ithink® Diagram
Info Labor Calc

4.3.5.1.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
info eng WTB	info WTB	chg info eng WTB	chg info eng WTB	info WTB/ week
info mgr WTB	info WTB	chg info mgr WTB	chg info mgr WTB	info WTB/ week

Table 4.33: Stocks and Flows - Info Labor Calc

The units of 'info WTB' correspond to the number of screenings, evaluations, corrective actions, validations, and assignments that information engineers and managers have to perform. On the average, an engineer or manager is able to perform a number of these per week. The stock represents the current level of work to be done (WTB) in the information sector. WTB is accumulated in stocks to prevent circular connections in the unavailability ratios and other parts of the model.

4.3.5.1.1.1 Stock Initial Values and Flow Equations

SI *info eng WTB = 0*

SI *info mgr WTB = 0*

F *chg info eng WTB = info eng work des - indo eng WTB*

F *chg info mgr WTB = info mgr work des - info mgr WTB*

4.3.5.1.2 Converters

Converter	Units	Inputs
info eng work des	info WTB	1. Mod CA in Progress 2. Proc CA in Progress 3. Reps Waiting for Screening 4. Evaluations in Progress 5. SOERs Waiting for Screening 6. Train CA in Progress 7. Prob Screening in Progress 8. Regulations Under Technical Review 9. Reg Eval In Progress 10. info eng WTB per reg 11. info eng WTB per eng per week
info mgr work des	info WTB	1. CA Waiting for Assignment 2. Evals Waiting for Validation 3. Proc CA Waiting for Val 4. Train CA Waiting for Val 5. Reg Reviews Waiting for Assign 6. info mgr WTB per reg 7. info mgr WTB per mgr per week
info eng unavail ratio	dimensionless	1. info eng WTB 2. eng info rev comp
info mgr unavail ratio	dimensionless	1. info mgr WTB 2. mgr info rev comp

Table 4.34: Converters - Info Labor Calc

The first two converters calculate the total amount of work within the information sector. Within these conversion calculations, NRC regulations must be multiplied by constants to convert regulation reviews and evaluations into consistent information work units. Info eng unavail ratio and info mgr unavail ratio are the two key ratios in the information sector. These are the ratios of work to be done in the information sector to the amount of information work completed.

4.3.5.1.2.1 Converter Equations

*info eng work des = Mod CA in Progress + Proc CA in Progress + Reps Waiting for Screening + Evaluations in Progress + SOERs Waiting for Screening + Train CA in Progress+Prob Screening in Progress + Regulations Under Technical Review+Reg Eval In Progress*info eng WTB per reg*info eng WTB per eng per week*

*info mgr work des = CA Waiting for Assignment + Evals Waiting for Validation + Proc CA Waiting for Val + Train CA Waiting for Val + Reg Reviews Waiting for Assign*info mgr WTB per reg*info mgr WTB per mgr per week*

info eng unavail ratio = IF (TIME<1) THEN (1) ELSE (info eng WTB+1)/(eng info rev comp+1)

info mgr unavail ratio = IF (TIME<1) THEN (1) ELSE (info mgr WTB+1)/(mgr infor rev comp +1)

4.3.5.1.3 Constants

Constant	Units
info eng WTB per reg	info WTB/reg
info mgr WTB per reg	info WTB/reg
info eng WTB per eng per week	info WTB/eng/week
info mgr WTB per mgr per week	info WTB/mgr/week

Table 4.35: Constants - Info Labor Calc

The first two variables are used in the conversion of regulation reviews and evaluations to appropriate amounts of work within the information sector. *Info eng WTB per eng per week* and *info mgr WTB per mgr per week* are constants that on the average, are the number of screenings, evaluations, etc., that an information worker can perform in a week. Managers have other administrative duties that distract from information review work, so they are able to do less information work in a week.

4.3.5.1.3.1 Constant Values

V *info eng WTB per reg = 25*

V *info mgr WTB per reg = 10*

V *info eng WTB per eng per week = 16*

V *info mgr WTB per mgr per week = 10*

4.3.5.1.4 External Variables

External Variable	Source Sub-Sector
Reps Waiting for Screening	Report Screening
SOERs Waiting for Screening	Report Screening
Prob Screening in Progress	In-Plant Problem Screening
Evaluations in Progress	Evaluation
Evals Waiting for Validation	Evaluation
CA Waiting for Assignment	Corrective Actions
Mod CA in Progress	Corrective Actions
Proc CA in Progress	Corrective Actions
Proc CA Waiting for Val	Corrective Actions
Train CA in Progress	Corrective Actions
Train CA Waiting for Val	Corrective Actions
Reg Reviews Waiting for Assign	NRC Regulation Dev.
Regulations Under Technical Review	NRC Regulation Dev.
Reg Eval in Progress	NRC Regulation Dev.
eng info rev comp	Engineer Allocation (in utility model)
mgr info rev comp	Manager Allocation (in utility model)

Table 4.36: External Variables - Info Labor Calc

Many of the external variables for this sub-sector are the stocks of work to be done or work in progress in the information sector. *Eng info rev comp* and *mgr info rev comp* are external variables that represent the amount of work available to be completed in the information sector. This is based on the amount of manpower available, productivity, overtime, and the amount of work they can perform in a week. Both of these are from in the manpower allocation sub-sectors in the plant.

4.3.5.2 Information Learning Curve

The most influential information use is its effect on reducing the causes or precursors of defects within the plant. Reducing defect causes helps to increase plant performance and improve safety. Both procedural and training corrective actions work to do this. More complete and correct procedures give mechanics, operators, and planners better guidelines for performing work that effects performance and safety. Training helps to make workers more informed, efficient and less error prone in their actions. Both of these effects can be thought of as reducing defect causes. In the plant model there are few direct places to make improvements for procedure training changes, so a learning curve was added to reduce defect causes from information learning. A standard system dynamics learning curve was used to for this. It is shown in Figure 4.14.

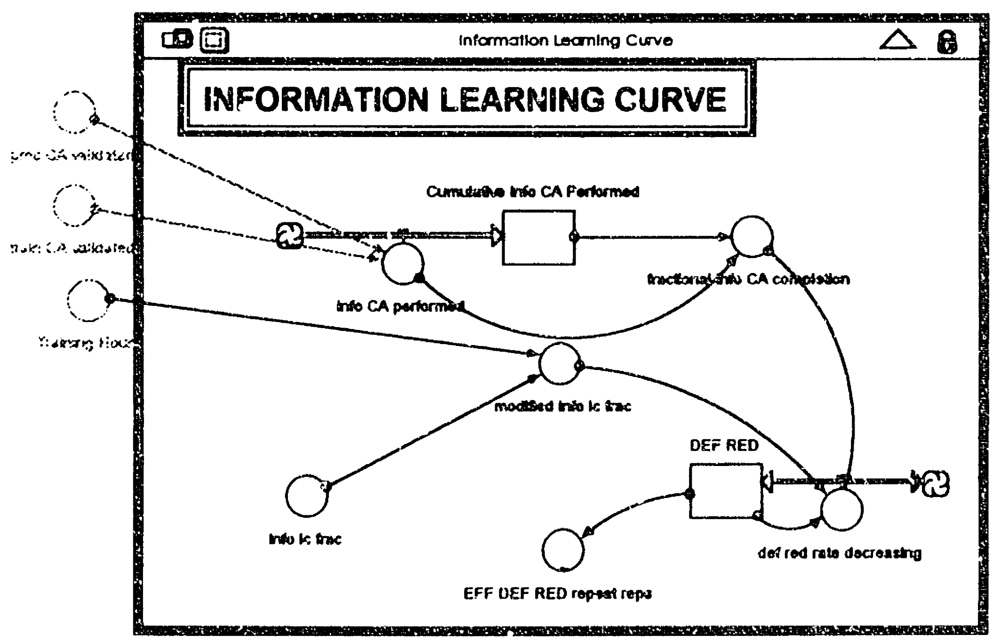


Figure 4.14: Ithink® Diagram
Info Learning Curve

4.3.5.2.1 Stocks and Flows

Stock	Units	Inflow	Outflow	Units
Cumulative Info CA Performed	CA	info CA performed		CA/week
DEF RED	dimensionless	def red rate decreasing		1/week

Table 4.37: Stocks and Flows - Info Learning Curve

Cumulative Info CA Performed is the cumulative number of procedure and training corrective actions performed in the information sector. It is given an initial value of five years of plant operation. *DEF RED* is a multiplier on all defect occurrences (operations, maintenance, breakdowns) that decreases because of the information learning. This represents the reduction of defect causes.

4.3.5.2.1.1 Stock Initial Values and Flow Equations

SI *Cumulative Info CA Performed = 30*52*5*

SI *DEF RED = .95*

F *info CA performed = proc CA validated + train CA validated*

F *def red rate decreasing = IF (TIME>5) THEN (-DEF RED*fractional info CA completion*modified info lc frac) ELSE (0)*

4.3.5.2.2 Converters

Converter	Units	Inputs
modified info lc frac	dimensionless	1. info lc frac 2. training hours
fractional info CA completion	dimensionless	1. info CA performed 2. Cumulative Info CA Performed
EFF DEF RED repeat reps	dimensionless	DEF RED

Table 4.38: Converters - Info Learning Curve

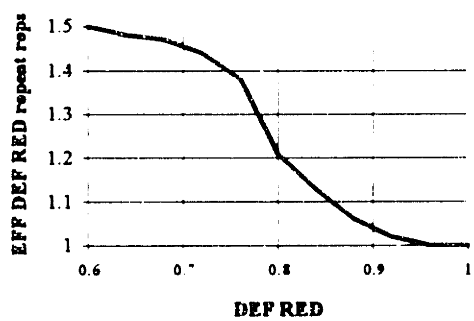
Modified info lc frac converts the learning curve fraction for use in decreasing the value of *DEF RED*. Within this converter, the information learning curve fraction is multiplied by the number of training hours for maintenance people. This reflects the fact that training must occur for the people to learn the new procedures and go through the new training practices. *Fractional info CA completion* is the ratio of corrective actions completed in the current week to the cumulative number of corrective actions. As this decreases, the learning curve becomes less steep. *EFF DEF RED repeat reports* increases the number of information reports that are repeats of previously screened reports.

4.3.5.2.2.1 Converter Equations

C *modified info lc frac = -LOGN(1-(info lc frac*training hours))/LOGN(2))*

C *fractional info CA completion = info CA performed/ Cumulative Info CA Performed*

C *EFF DEF RED repeat reps = GRAPH(DEF RED)*



4.3.5.2.3 Constants

Constant	Units
info lc frac	dimensionless

Table 4.39: Constants - Info Learning Curve

This *info lc frac* is the fractional reduction in defect causes for a doubling of cumulative corrective actions performed.

4.3.5.2.3.1 Constant Values

info lc frac = 0.025

4.3.5.2.4 External Variables

External Variable	Source Sub-Sector
proc CA validated	Corrective Actions
train CA validated	Corrective Actions
training hours	Mechanics (in utility model)

Table 4.40: External Variables - Info Learning Curve

The corrective actions that effect this learning curve originate in the corrective action sub-sector of the information sector. This strength of the learning curve is largely influenced by the number of training hours being performed at the plant per week.

4.3.5.3 Information SALP Effect

The last sub-sector of the information sector calculates the direct effect of using information on SALP score. Because it could improve performance and safety, the NRC believes using information is a sign of good management behavior,. For this reason, if the reports are analyzed correctly (applicable information is put to use), the NRC will increase parts of the SALP score. This sub-sector is not be explained in detail. It tracts the number of available reports and the reports/information that are abandoned because of lack of manpower. The ratio of reports completed to total reports (report analysis ratio) is used in a converter that effects the SALP score in the plant model. Additionally, unused reports are saved in this sub-sector, and can be reopened for future use. This sub-sector diagram is in Figure 4.15.

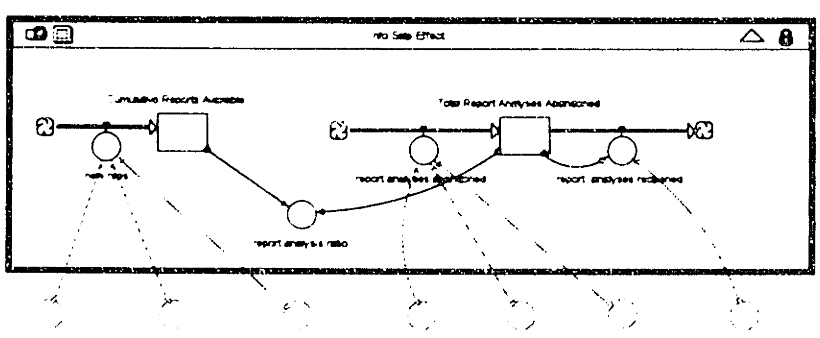


Figure 4.15: Ithink® Diagram
Info SALP Effect

Chapter 5

5.0 Utility Model Simulations

The utility model was created to simulate the dynamics of a real nuclear power plant and utility operations. It produces the dynamic interactions of a nuclear power plant with the social, political, financial, and information environments. The model represents an electric utility with one nuclear unit. Different sets of controllable system variables can be used to study model behavior and responses to various utility manager actions.

The model simulations should not be believed as exact predictions of future behavior. The model is not precise enough to make such a claim. In fact, many of the model variables have not been validated to data within the industry. Variables can become distorted for many reasons. A model builder's views or opinions may bias a variable such as how worker overtime affects hiring. There is a lack of available or obtainable data like important financial numbers. Additionally, many complex relationships have been simplified for modeling purposes. For instance, the is direct relationship between NRC regulations and increased inspections. Because of this inaccuracy, the model output should be viewed only as a general guide of utility behavior and not as exact tool for making decisions. Placing too much emphasis on the numerical output within the model could be extremely misleading. The model will be ready to produce more accurate results when data is obtained from a utility and model results are validated to that particular utility's history. Remember, the purpose of this thesis was to provide the relationships and structure for information exchange and use within the industry, not to obtain exacting results.

This chapter will present simulations of the utility model to show its performance. Three different model scenarios will be run. Because it takes only ten minutes on a 486DX2-66Mhz PC for a full simulation, many others can easily be simulated. The first will be steady-state, in which there are no abnormal occurrences within the model. The second simulation will be an abnormal situation in which an accident the level of TMI occurs at another nuclear power plant. There are two cases within each of these scenarios. In the first case, the fraction of engineers allocated to information is set to zero the whole simulation, and in the other it is increased to 30% at week 52. Other manager decisions, such as training budget, will be unchanged. This will allow the reader to see only the intended effects of information use. The last simulation presented will further vary the amount of staff allocated for information work to test the model's sensitivity.

Not all variables from the model will be discussed. To show behavior responses, a few important variables will be presented in comparative graphs over time. Each simulation is run for ten years with delta time set at one quarter of one week. The first 52 weeks of model simulation can be ignored because the model is not yet in equilibrium. The simulations were run in 'sensitivity mode', so that two cases could be graphed together. Throughout the discussions the cases with information use will be referred to as IUP (Information Use Plant) and without as NIUP (Non-Information Use Plant).

5.1 Steady-State

This section presents the steady-state simulation of the utility model. Steady-state refers to a situation in which the utility operates in a stable social and political environment (no changes in opposition, etc.), stable financial environment (PUC gives desired rate of return and no competition), and no major accidents within the industry. In order to show the operation of the information sector, graphs of variables in it will be presented first. The rest of this section will be devoted to graphs and explanations of the benefits and costs of information use in a steady state situation.

5.1.1 Information Sector

The information sector graphs are taken from the IUP. These graphs will show that the information sector is functioning as expected. Graphs of the identified industry problems, reports produced, and flows from information processing will be shown for this purpose.

Remember that identified problems is the converter that represents the number of problems identified from the different event types in the industry. These events were determined randomly in the Industry Events sub-sector, and multiplied times a number of problems per event to get the number of identified problems. The behavior of this variable is shown in Figure 5.1. Each unusual event produces one new problem identified. Approximately every other week, or one in about every ten event occurrences, a site alert occurs and identifies ten problems. Sometimes, multiple alerts can occur in a week, reflected by a higher number of identified problems. Site emergencies occur approximately once every three years, and are shown when one hundred problems are identified. Changing the seed variable for the random processing of events can change this particular behavior, but Figure 5.1 represents what typically happens during the simulation for identifying problems.

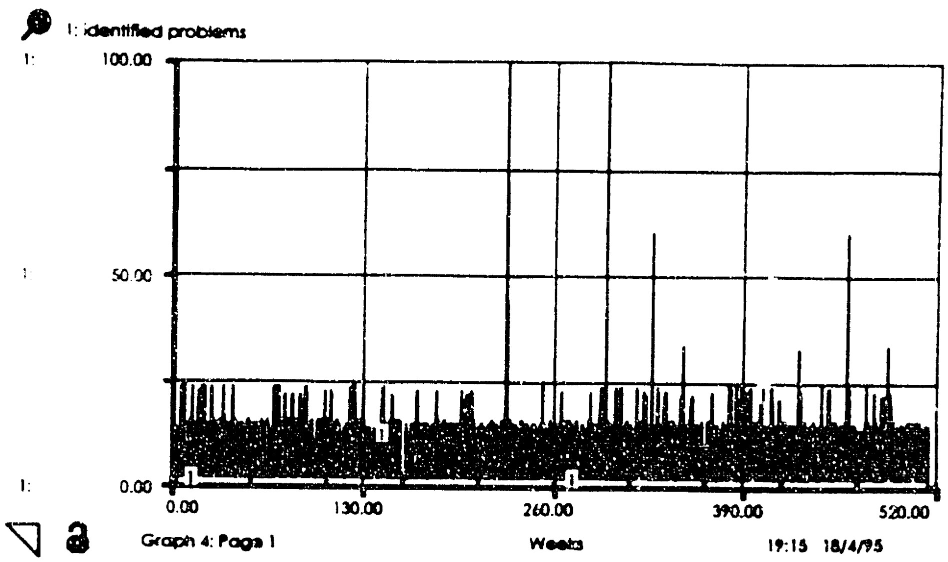


Figure 5.1: Identified Problems [problems/week]
Steady State - Frac of Engs Allocated to Info = 0.30

It is expected that reports on these problems will follow the pattern of identified problems. This is shown in Figure 5.2, the graph of reports coming from the INPO SEE-IN network. Peaks in reporting levels occur when there are increases in problem reporting. Moreover, there are time delays in the report production. SEN's are produced almost immediately after the problems are identified. SER's follow with a slight time delay for the completion of analyses and reports and because of investigations into recommendations, SOER's follow with an even longer time delay.

Figure 5.3 shows the flows of report screenings and evaluations in the information sector. No screening takes place until week 52, when the 30% of the engineers are allocated. There are slight increases in these flows after the peaks of incoming information. However, these peaks are not that large because information processing is limited by manpower availability. Had the time delays in the information sector not been adjusted for engineer availability, these peaks of information work would be more apparent. But this would lead one to believe that the information sector is overstaffed because processing is too quick. In this case, because processing is limited, the flows are relatively constant.

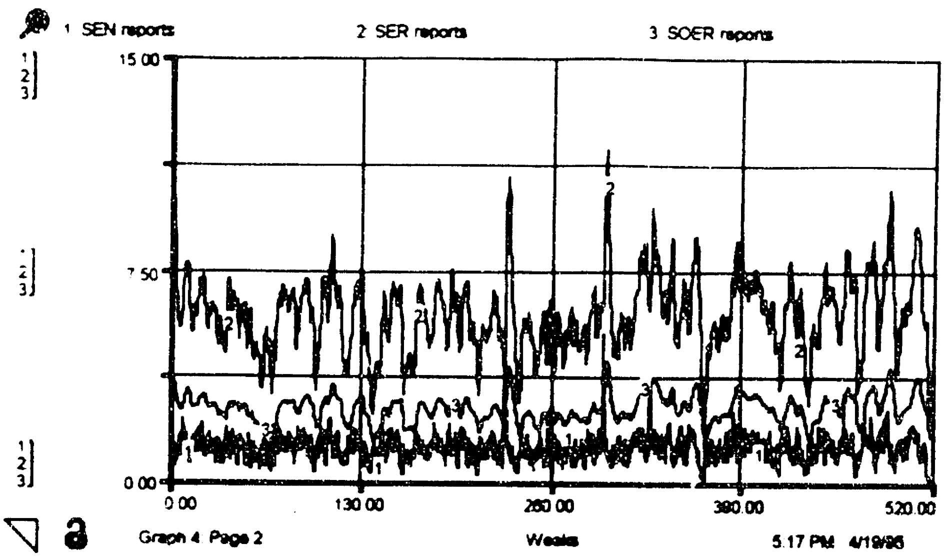


Figure 5.2: INPO Reports [reports/week]
Steady State - Frac of Engs Allocated to Info = 0.30

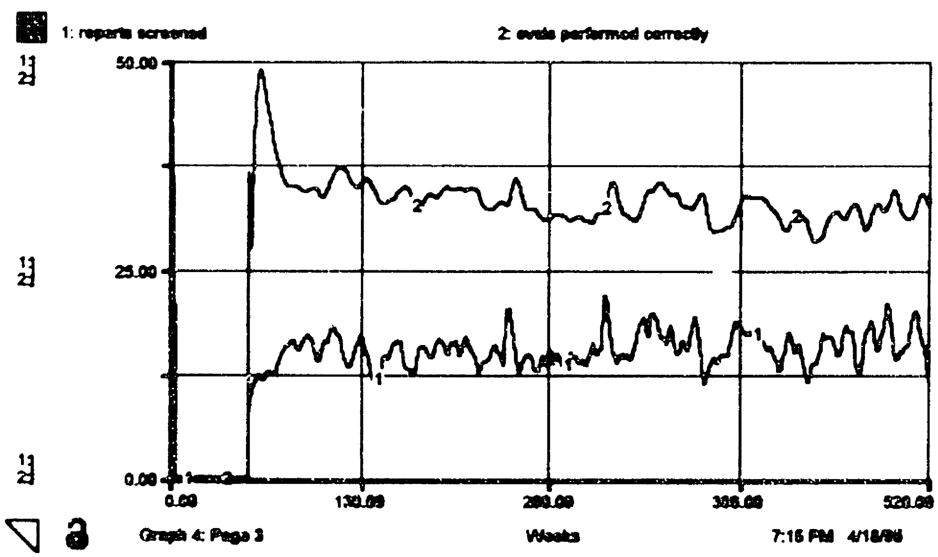


Figure 5.3: Report Screening and Evaluation [reports/week]
Steady State - Frac of Engs Allocated to Info = 0.30

Correct evaluations lead to corrective actions within the plant. These corrective action flows are relatively constant. This is because time delays preceding and during corrective actions smooth out the information flows. The graph of the corrective actions flows is shown in Figure 5.4. These corrective actions reduce defect causes through the information learning curve.

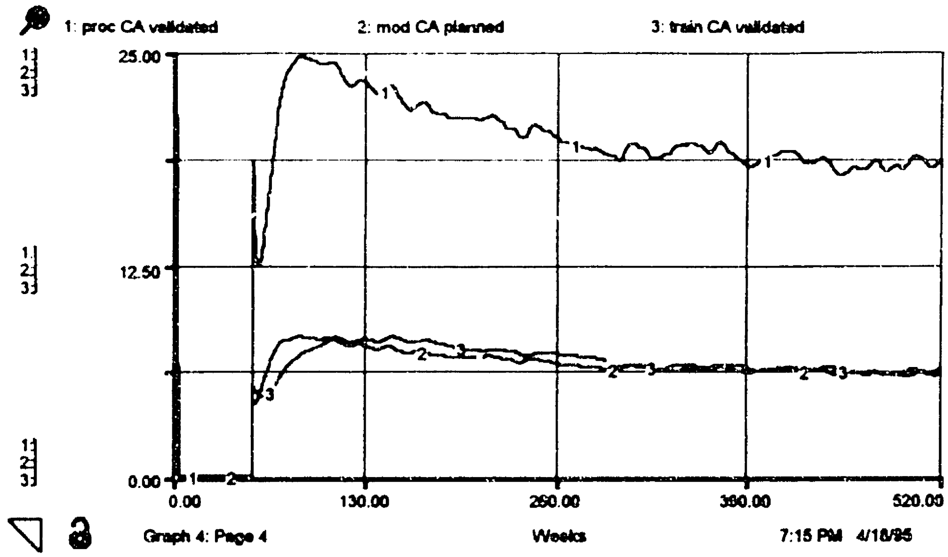


Figure 5.4: Corrective Action Flows [CA/week]
Steady State - Frac of Engs Allocated to Info = 0.30

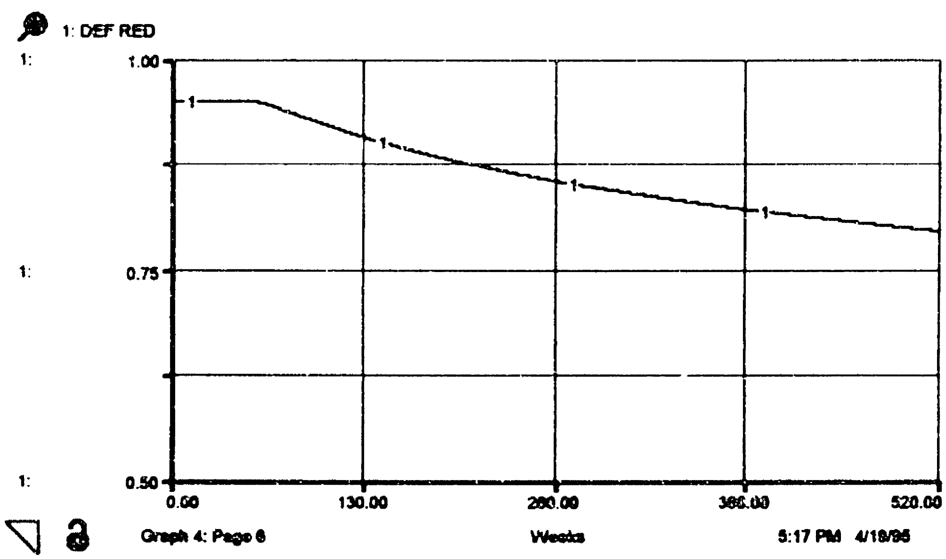


Figure 5.5: Multiplier on Defect Causes
Steady State - Frac of Engs Allocated to Info = 0.30

This learning curve produces a multiplier (DEF RED) on all defect causes. It is shown in Figure 5.5. Defects are reduced by 15% over the 9 years that the information system is in effect. The learning curve is stronger at the beginning of information work, because the number of corrective actions being performed in a week is high compared to the cumulative number already performed. There is less to learn when many corrective actions have already been performed.

5.1.2 Utility Model

To reiterate, two cases were run in this steady-state scenario. In the first, no engineers were allocated to performing information work and in the second 30% of the engineering staff (and 15% of the management staff) were allocated to performing information work at week 52. This section will present the benefits and costs of using information at the utility. Graphs of the plant's capacity online, defects, net income, labor costs, core melt frequency and SALP score will be shown.

When the engineers are removed from maintenance work to do information work (at week 52) there is a drop in capacity online. This is shown in Figure 5.6. The 80 week drop in capacity is because engineers and managers are taken away from reviewing maintenance work orders in the plant. This creates delays in the processing of work orders to fix broken equipment and perform scheduled maintenance. Simultaneously, learning from information is causing defect generation to decrease in the plant. Figure 5.7 is a graph of all new defects occurring in the plant. At week 140, the IUP has as high of a capacity online as the NIUP. Because there are fewer defects, there is less maintenance work to do, so the lack of engineers working on maintenance no longer hurts plant operations. The IUP gradually increases capacity, because less equipment is breaking down and being taken down for maintenance and inspections. Additionally, there are enough maintenance personnel to fix the reduced number of problems. The capacity at the IUP is 3% higher at the end of the simulation than the NIUP. The short term loss in capacity, due to the re-allocation of personnel, is made up in long term gains.

This is a good example of the non-linearities and time delays in the model. Plant defects decreases over 10%, while capacity only increases 3%. Also, there is the time delay before the positive effect of implementing information can be seen on important plant variables, such as capacity.

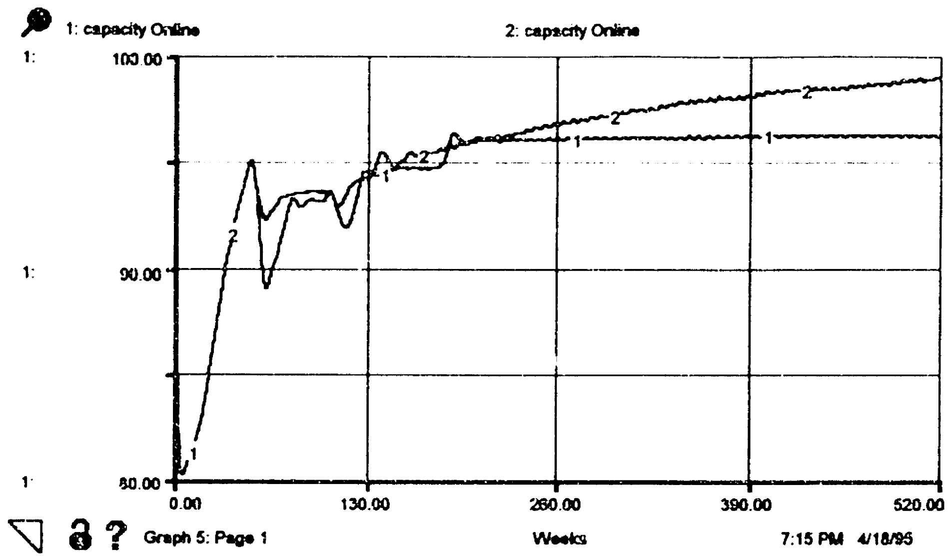


Figure 5.6: Capacity Online
Steady State - Frac of Engs Allocated to Info [0.0., 0.30]

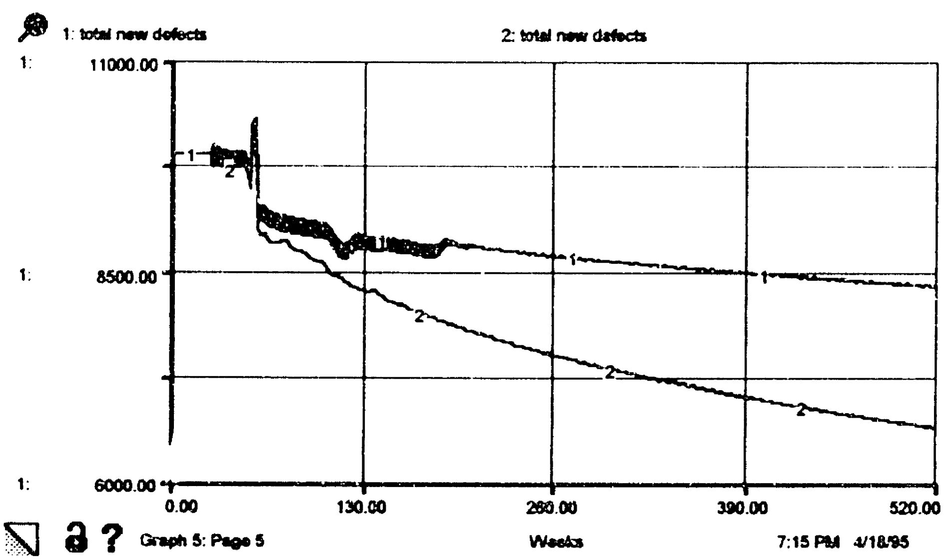


Figure 5.7: Total New Defects [defects/week]
Steady State - Frac of Engs Allocated to Info [0.0., 0.30]

Net income of the utility follows capacity online almost directly. This is because Net Income is extremely dependent on the plant producing power. The better the plant runs, the more power it produces, and the utility is able to sell all of the power it generates. This increases revenues, and hence, net income significantly. The pattern of short term loss and long term gain for net income is presented in Figure 5.8. It shows that the plant with a higher capacity has a higher net income.

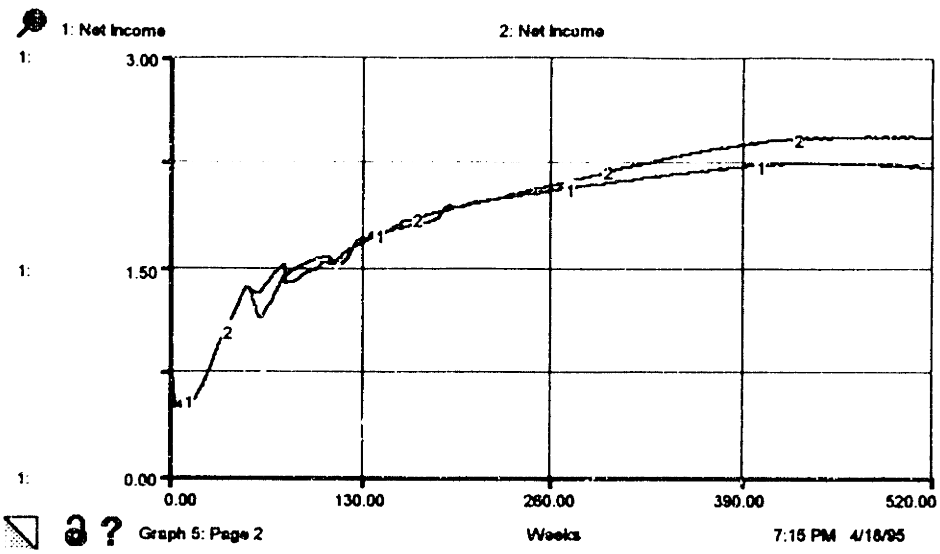


Figure 5.8: Net Income [$ million/week]
Steady State - Frac of Engs Allocated to Info [0.0., 0.30]

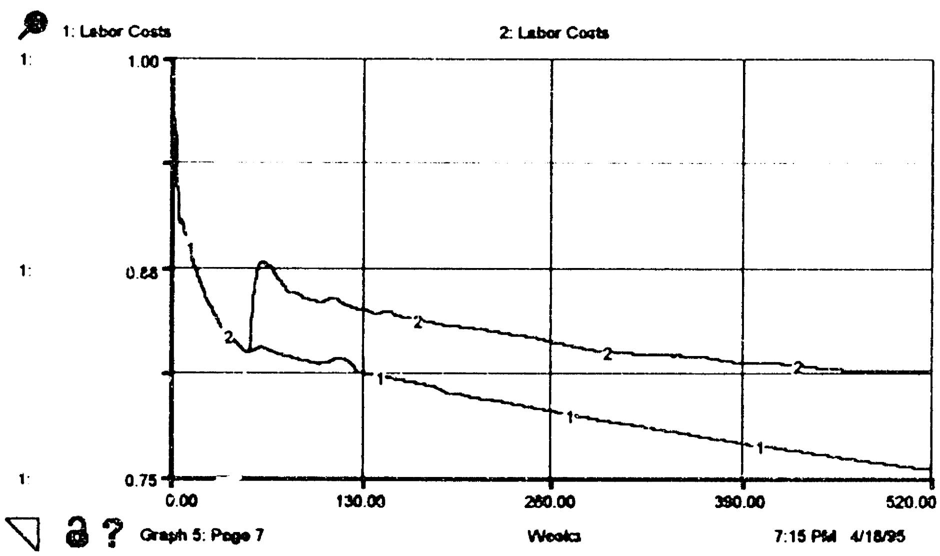


Figure 5.9: Labor Costs [$ million/week]
Steady State - Frac of Engs Allocated to Info [0.0., 0.30]

The net present value of the net income (at 3% interest) is $827 million without information, and $855 million with information use. Clearly, the long term gain in net income overcomes the short term loss. The gain in revenues from increased capacity overcomes the increased labor costs involved in using information. The labor costs are shown in Figure 5.9. The IUP has higher labor costs of $100,000 per week. This is from increased engineer overtime to perform maintenance and information work.

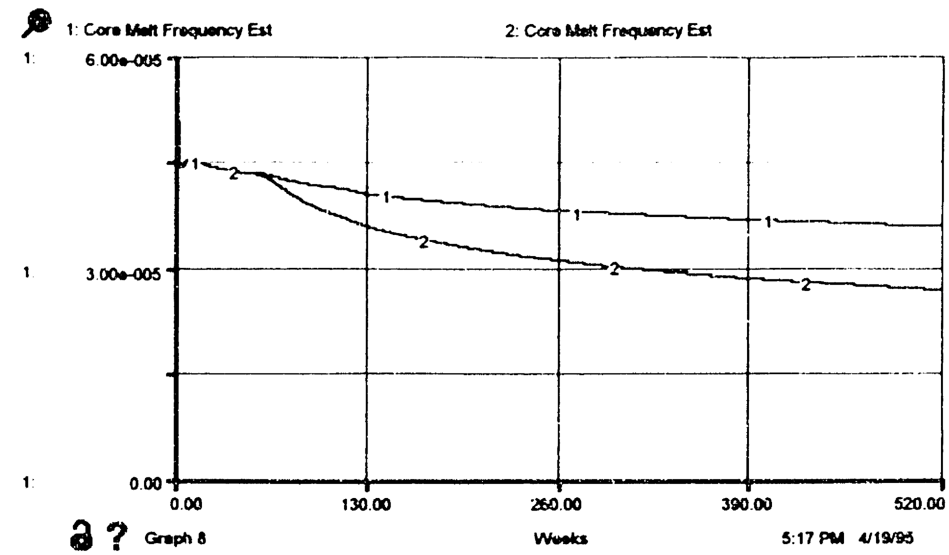


Figure 5.10: Core Melt Frequency Estimation [1/reactor-years]
Steady State - Frac of Engs Allocated to Info [0.0., 0.30]

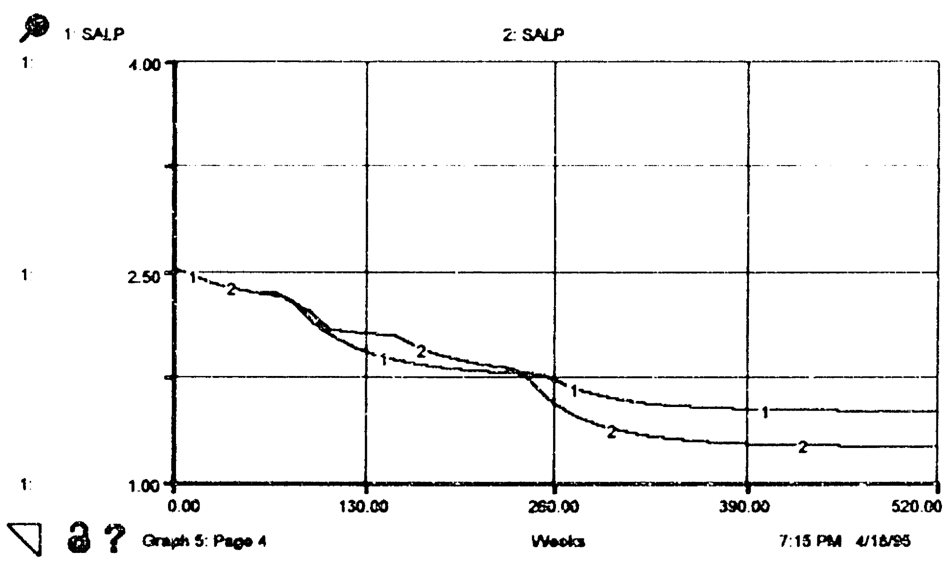


Figure 5.11: SALP score
Steady State - Frac of Engs Allocated to Info [0.0., 0.30]

There is also need to have more managers in the plant for performing information work. Again, the increased labor cost is offset by revenue gains.

Core melt frequency is heavily dependent on defects within the plant. As defects decrease and less breakdowns occur, there is a lessor chance of the core melt accident. By reducing defect occurrences, using information helps to improve the core melt frequency. IUP experiences a 30% decrease in the frequency of core melt. This is shown in Figure 5.10.

Using information has a benefit on SALP score also. Figure 5.11 shows this delayed result. At first, the SALP score is worsened (a higher value is worse) because personnel workload in the plant increases and capacity decreases. Eventually, workload decreases, and capacity rises to better the SALP score. Additionally, the NRC raises the SALP score directly because the utility is attempting to use the available information.

5.2 Event

This section presents the abnormal occurrence simulation of the utility model. In this scenario, an accident occurs at another utility in week 156. It is assumed that this accident has the same impact on the industry as Three Mile Island. This accident affects the industry by increasing social and political actions such as public concern and NRC investigations. The utility is adversely affected by these, and other accident feedbacks. Again, in this scenario there will be no information usage in the first case (NIUP) and usage (IUP) in the second. This scenario will help to understand how consistent information use before a major event could help a utility minimize the adverse effects an event could have on the utility.

Because of the event, the NRC will require the utility to perform more mandatory inspections of equipment. This increase in mandatory inspections occurs in four stages. In order of occurrence, these are: investigations, reports, regulations in development, and regulations on books. Mandatory inspections significantly increase the amount of equipment being taken down for inspections, and the number of defects discovered. Consequently, capacity is lowered. In addition to this mandatory inspection increase, NRC actions also take personnel away from normal plant activities, lowering capacity further.

5.2.1 Utility Model

Before the accident occurs in week 156, the utility operates exactly the same as it did in the steady state scenario. Capacity online is shown in Figure 5.12, and is the same as the steady state scenario till week 156. After the accident, the effects of regulations are appear in both cases. However, the effects are more extreme on the NIUP. Capacity for the IUP is 10% higher than the NIUP after the accident. In addition, notice that the utility using information finishes at a slightly higher capacity than the steady-state case because of all the information it processes. At the end of the simulation, the NIUP still hasn't

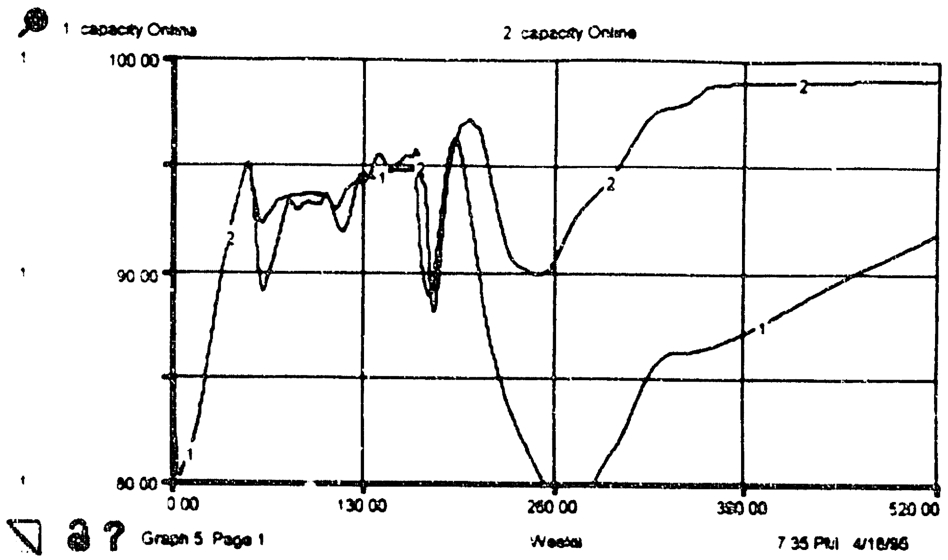


Figure 5.12: Capacity Online
Major Event at Other Utility- Frac of Engs Allocated to Info [0.0., 0.30]

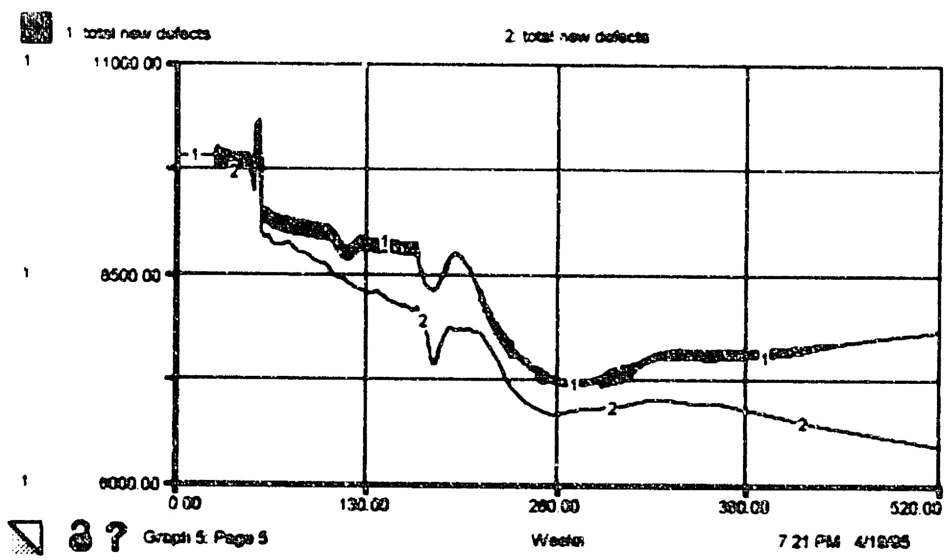


Figure 5.13: Total New Defects [defects/week]
Major Event at Other Utility - Frac of Engs Allocated to Info [0.0., 0.30]

recovered to the capacity level it reached in the steady-state scenario because of the NRC's influence. Defects in the NIUP case were less than they were in the steady-state case because of the plant's lower capacity. Defects are less in the IUP because the increased information from the accident increases learning.. New defects are presented in Figure 5.13.

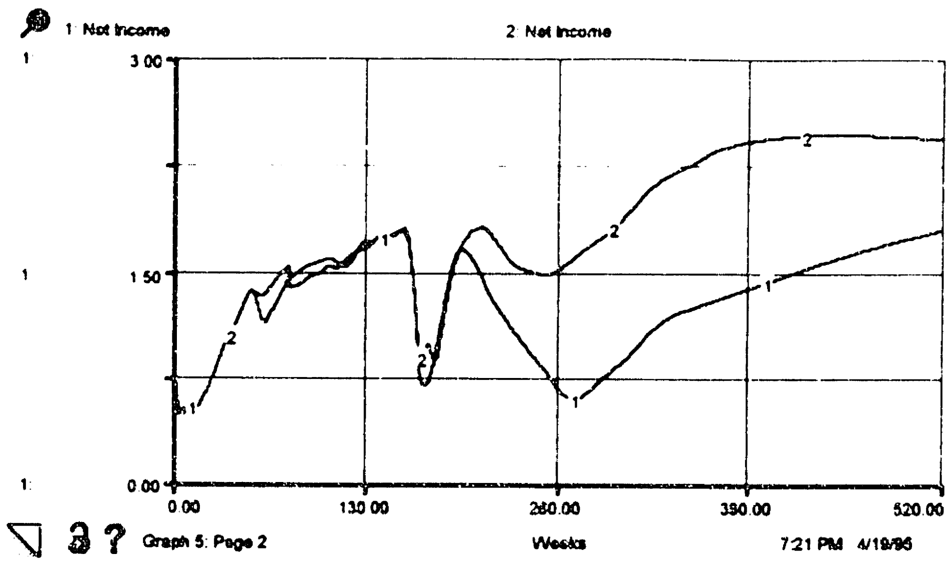


Figure 5.14: Net Income [$ million/week]
Major Event at Other Utility - Frac of Engs Allocated to Info [0.0., 0.30]

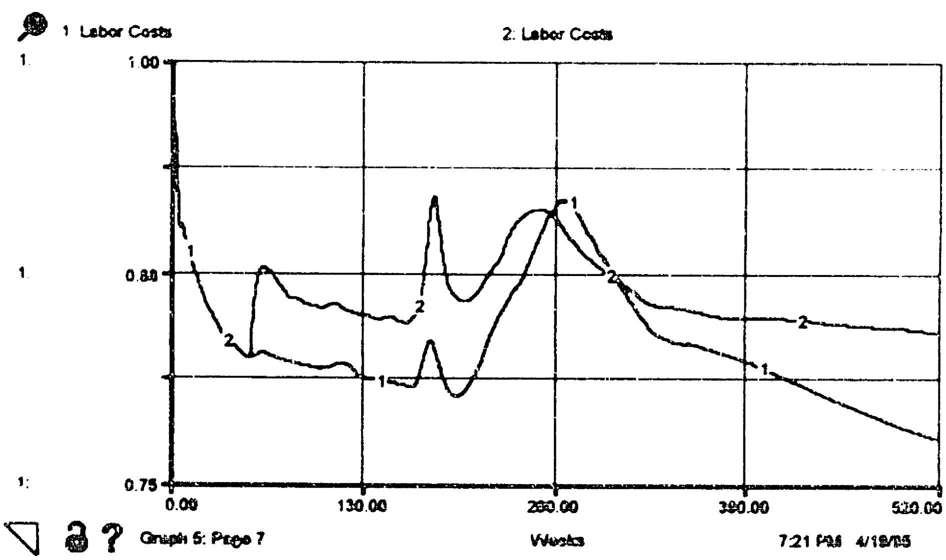


Figure 5.15: Labor Costs [$ million/week]
Major Event at Other Utility - Frac of Engs Allocated to Info [0.0., 0.30]

Again, net income closely follows capacity. In this scenario the IUP has a significantly higher net income, because it maintains a much higher capacity. This net income increase is shown in Figure 5.14. The net present value of this net income (at 3% interest) is $572 million for the utility not using information and $789 million for the utility using it. As before, IUP has higher labor costs throughout the majority of the simulation. However,

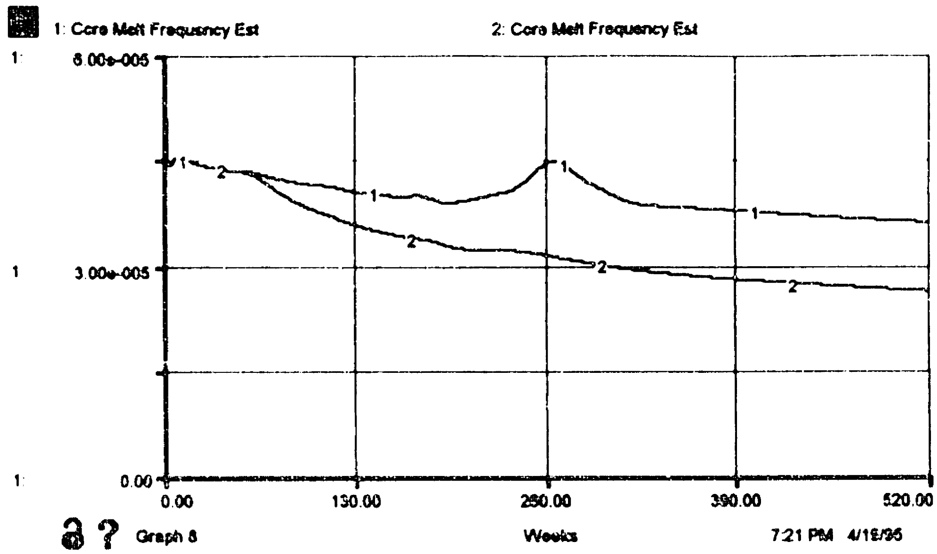


Figure 5.16: Core Melt Frequency Estimation [1/reactor-years]
Major Event at Other Utility - Frac of Engs Allocated to Info [0.0., 0.30]

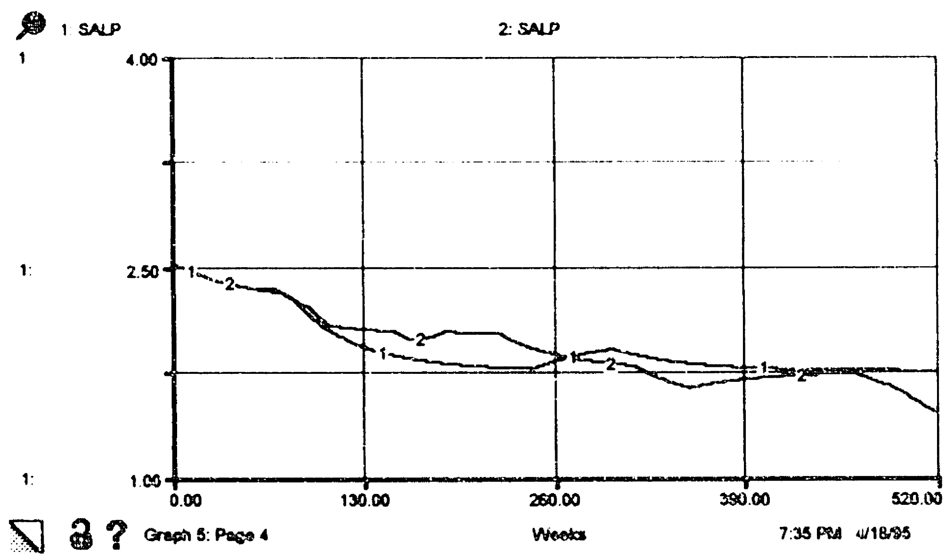


Figure 5.17: SALP Score
Major Event at Other Utility - Frac of Engs Allocated to Info [0.0., 0.30]

during the largest increase of inspections (from NRC regulations), the utility without information usage has higher labor costs. This is because of high amounts of overtime forced on maintenance workers to perform the mandatory inspection work and ensuing maintenance. The labor costs are shown in Figure 5.15.

Figure 5.16 shows the effects of the event and information use on core melt frequency. Again, information use causes a 30% decrease in the frequency because of the lowering of defects. The utility not using information experiences an increase in this frequency during the period of inspections. This is because of the high amount of equipment being taken down, which makes the plant more vulnerable.

Neither utility is able to reach as high of a SALP score as the one obtained in the steady-state scenario. One of the reasons for this is that the NRC causes higher personnel workloads, which is a key factor in the computation of SALP score because heavily worked employees have lower productivities. Figure 5.17 presents the SALP scores for the simulation. It takes longer to see the direct effect of using information on the SALP score because of the many effects that the NRC had on the plant.

5.3 Model Sensitivity to Worker Allocation

The third scenario will be steady-state, in which the fraction of engineers allocated to information work is varied from 0% to 45%. This will show interesting feedbacks of different staff allocation. Again, because of numerical uncertainties in the model, these results should not be studied as exact guidelines for utility decisions. The results are shown to depict interesting feedback in the model.

5.3.1 Utility Model

These simulations were run at steady state. The fraction of engineers allocated to information work was set to zero until week 52. At week 52, it was then set to 0%, 15%, 30%, and 45%.

Figure 5.18 shows the effect of varying the number of information engineers on capacity online. When too many engineers are allocated to information in the 45% case, the benefit of reducing defects is too delayed to have a positive effect on capacity. Because so many engineers are taken away from maintenance, the plant does not complete enough maintenance work to maintain capacity. Eventually, after almost 9.5 years, the reduction in defects helps the plant to run better than the 0% information utility, but too much capacity was already lost. For this model setup, the 15% case is an improvement over the 30% case. This is because fewer maintenance engineers are taken away for information work, so the plant performs more maintenance during the information 'learning period.' This shows feedback of allowing more maintenance work to be done. Remember, that this was run during steady-state. It is possible, that if an event occurred the 30% case would be better because information manpower would exist to process all the incoming information.

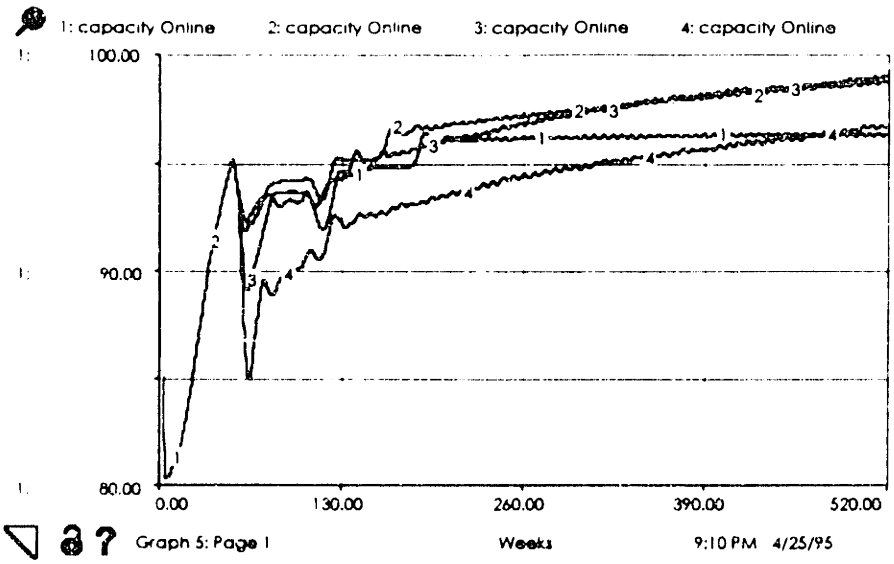


Figure 5.18: Capacity Online
Steady State - Frac of Engs Allocated to Info [0.0., 0.15, 0.30, 0.45]

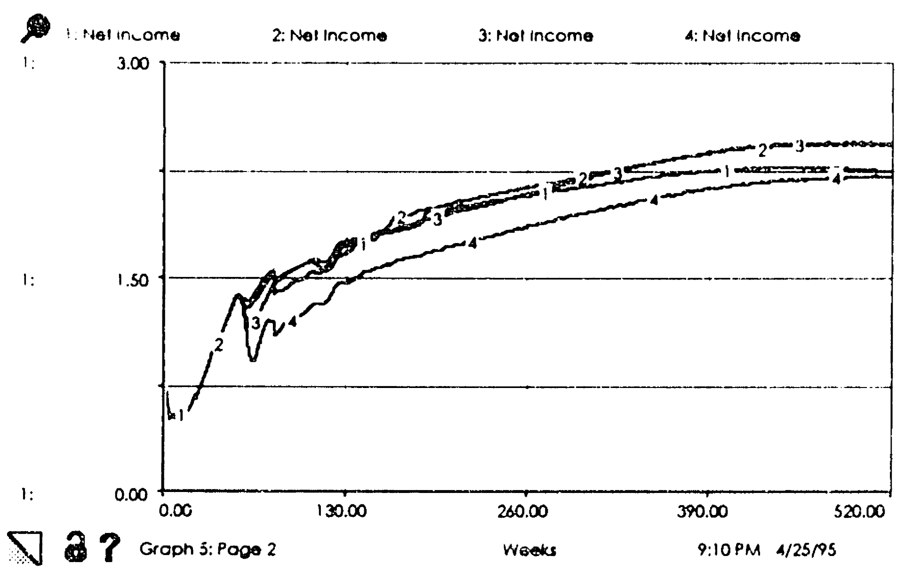


Figure 5.19: Net Income [$ million/week]
Steady State - Frac of Engs Allocated to Info [0.0., 0.15, 0.30, 0.45]

Net income is shown in Figure 5.19. As expected, net income follows capacity. The utilities that run the plants better have higher revenues that can offset the additional labor costs. The net present values of net income for these cases are shown in Table 5.1. The second case of 15% has a higher NPV than the others because it is consistently running at a higher capacity.

% Allocated to Information	NPV [$ million]
0 %	$ 827
15 %	$ 859
30 %	$ 853
45 %	$ 759

Table 5.1: Net Present Value (at 3%/year)
Variation of % Information Allocation

Chapter 6

6.0 Summary and Conclusions

This thesis is the last addition to the nuclear utility model. System dynamics enabled the modeling of various information-feedback relationships that exist for a nuclear utility. Relationships for plant operations, the social and political environment, the financial environment, and information exchange are modeled and interconnected in the complete utility model. All of these relationships combine to create a model that represents the dynamics of a nuclear utility and the environment in which it operates.

The nuclear industry's information exchange is studied extensively within this thesis. The system dynamics work in this thesis models the creation of information, the utility's subsequent information analysis, and the effects of its use. All of these relationships are connected to the utility model as the information sector. Adding the information sector to the model gives it the ability to produce the dynamic costs and benefits of using information at the utility. The main issue in using information is the allocation of professional staff to perform the information work. The utility's budget limits the number of workers in the plant. Consequently, allocating workers to information takes them away from performing maintenance. Hence, correct allocation of workers is a key model variable.

Two different model scenarios, steady-state and TMI-like event, were studied. In both scenarios two separate cases were run to see the effects of information usage. The first case did not allocate engineers to information work, and the second allocated 30% of the engineering staff to information. This made it easy to view the effects of information on the utility, and see if the benefits of information use are greater than its costs. Remember, the major benefit of using information is the reduction in the causes of defects. In comparison, maintenance work only fixes defects that have already occurred.

In the steady-state scenario there is a one and a half year delay before information benefits become apparent in the plant's capacity. This occurs because the removal of personnel from maintenance work delays the completion of necessary maintenance. Once defects are reduced by information enough, the capacity of the information-using plant begins to increase. This is because defects are decreasing, and the smaller maintenance staff is able to complete the reduced level of maintenance. The capacity of the information-using plant constantly improves because it is reducing defects. In contrast, the plant not using information runs at a constant capacity, as it is not reducing the causes of its problems. The information-using plant experiences long-term gains in higher capacity over the non-information plant. Capacity is directly tied to revenues, so the plant using information has a long-term gain in revenues over the simulation period. This revenue increase is much greater than the additional labor costs involved in using information and also greater than the losses in revenues during the period of lowered capacity. In addition to performance gains, the plant's safety improves, as its core melt frequency falls by 30%. Improving safety helps to reduce public opposition, which strongly affects many strong social/political factors. Another delayed positive effect is as an improved SALP score. Improving the SALP raises the plant's perceived safety in the eyes of investors and the government. The pattern of short-term loss leading to a long-term shown in this scenario is common in system dynamics, as it is in real-life.

In the other scenario, an exogenous variable created a major event at another nuclear power plant. Numerous NRC and public actions, which have significant impacts on the utility, are initiated by the occurrence of the event. NRC actions force the plant to increase inspections which lead to discovery of more defects in the plant. Discovering defects increases takedowns of broken equipment for maintenance work, which lowers capacity. Both the information-using and non-information plants experience increased takedowns and maintenance work because of the NRC's actions. However, the plant with fewer defects, the information-using plant, discovers fewer defects and does not need to perform as much maintenance work as the non-information plant. Therefore, it is able to maintain a higher capacity because there is less broken equipment to discover. The information-using plant, with fewer defects in equipment, is in a better position to survive the wrath from governmental actions from an accident. This scenario shows that there is great benefit in using information to reduce defects because it leaves the utility better prepared to handle government responses to an accident in the industry.

There is much future work needed on the utility model before it can be used as a reliable tool for making accurate managerial decisions. The causal loop relationships and Ithink® modeling represent operations, policies and decision making in the nuclear industry. However, the complete utility model is extremely general. Many of the processes modeled in the utility, such as evaluation of information, are utility specific in real-life. Refinement of these processes is necessary to truly depict behavior of a certain utility. Much data in the model is general or average industry data. Many relationships could be better represented in the model if a utility would be willing to provide the needed information. There are also numerous relationships that have been simplified in the model. Using these without justification could create misinterpretations of utility behavior and responses.

These relationships, such as the NRC's effect on the plant, must be studied further to refine them and validate their correctness. To put it simply, the general utility model needs to be customized to an operating utility, and results should then be evaluated against historical data to validate the model. Once this is accomplished, the model could be used as a tool to make accurate decisions.

The utility model does have practical applications. Because the information-feedback relationships in the model do reflect a simple view of reality, it can be used to study the dynamics of various decisions. Some of these possible decisions are: information use, preventive maintenance, training, budgeting, labor, and capital investment. This thesis presented the dynamic impact of one of these decisions, information use.

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Industry Events

- base_prob_sa = 10
- base_prob_se = .25/2
- events_per_year = 140
- identified_problems = unusual_event*probs_disc_per_unusual_event+site_alert*prob_disc_per__alert+site_emergencies*prob_disc_per_emergency+problems_from_major_event
- ident_prob_ratio = SMTH1(identified_problems,2,1)/SMTH1(identified_problems,time_horizon_to_comp_ind_probs,10)
- problems_from_major_event = IF (TIME=158) AND Event_Switch=1 THEN 1000 ELSE 0
- probs_disc_per_unusual_event = 1
- prob_disc_per_emergency = 100
- prob_disc_per__alert = 10
- rand_for_num_events = RANDOM(0,1,rand_seed+1000)
- rand_seed = 4000
- time_horizon_to_comp_ind_probs = 12
- EFFidprobEPRI = GRAPH(ident_prob_ratio)
  (1.00, 1.04), (1.10, 1.10), (1.20, 1.10), (1.30, 1.10), (1.40, 1.12), (1.50, 1.16), (1.60, 1.26), (1.70, 1.62), (1.80, 2.37), (1.90, 3.32), (2.00, 5.00)
- EFFidprobWANO = GRAPH(ident_prob_ratio)
  (1.00, 1.00), (1.10, 1.01), (1.20, 1.02), (1.30, 1.02), (1.40, 1.03), (1.50, 1.04), (1.60, 1.05), (1.70, 1.09), (1.80, 1.16), (1.90, 1.30), (2.00, 1.49)
- EFFsitealandemerg_NRCins = GRAPH(SMTH1(site_alert+10*site_emergencies,12,1))
  (1.00, 0.00), (1.40, 0.00), (1.80, 0.00), (2.20, 0.002), (2.60, 0.017), (3.00, 0.034), (3.40, 0.048), (3.80, 0.072), (4.20, 0.105), (4.60, 0.148), (5.00, 0.196)
- event_occurrences = GRAPH(rand_for_num_events)
  (0.00, 1.00), (0.05, 1.00), (0.1, 1.00), (0.15, 1.00), (0.2, 1.00), (0.25, 1.00), (0.3, 1.00), (0.35, 2.00), (0.4, 2.00), (0.45, 2.00), (0.5, 2.00), (0.55, 3.00), (0.6, 3.00), (0.65, 4.00), (0.7, 4.00), (0.75, 4.00), (0.8 5.00), (0.85, 5.00), (0.9, 5.00), (0.95, 6.00), (1.00, 6.00)

Event_Processing = Event_Pool
INFLOWS:
- event_pool_reset = PULSE(events_per_year,1,52)-PULSE(Event_Pool,52,52)

OUTFLOWS:
- unusual_event = unusual_event'
- site_alert = site_alert'
- site_emergencies = site_emergencies'

Event_Pool(t) = Event_Pool(t - dt) + (event_pool_reset' - site_emergencies' - site_alert' - unusual_event') * dt
INIT Event_Pool = 0
INFLOWS:
- event_pool_reset' = event_pool_reset

OUTFLOWS:

```
site_emergencies' = se
site_alert' = sa
unusual_event' = event_occurance-site_alert'-site_emergencies'
event_occurance = event_occurrences
rand_1 = RANDOM (0,100,rand_seed+100)
rand_2 = RANDOM (0,100,rand_seed+200)
rand_3 = RANDOM (0,100,rand_seed+300)
rand_4 = RANDOM (0,100,rand_seed+400)
rand_5 = RANDOM (0,100,rand_seed+500)
rand_6 = RANDOM (0,100,rand_seed+600)
sa = (test_1+test_2+test_3+test_4+test_5+test_6)
sa_prob_lim = 100-base_prob_sa
se = test_10+test_11+test_12+test_7+test_8+test_9
se_prob_lim = 50-base_prob_se
test_1 = IF (event_occurance<1) OR (rand_1<(sa_prob_lim)) THEN (0) ELSE (1)
test_10 = IF (event_occurance<4) OR (rand_4<(se_prob_lim)) OR (rand_4>50) THEN (0) ELSE
(1)
test_11 = IF (event_occurance<5) OR (rand_5<(se_prob_lim)) OR (rand_5>50) THEN (0) ELSE
(1)
test_12 = IF (event_occurance<6) OR (rand_6<(se_prob_lim)) OR (rand_6>50) THEN (0) ELSE
(1)
test_2 = IF (event_occurance<2) OR (rand_2<(sa_prob_lim)) THEN 0 ELSE (1)
test_3 = IF (event_occurance<3) AND (rand_3<(sa_prob_lim)) THEN (0) ELSE (1)
test_4 = IF (event_occurance<4) OR (rand_4<(sa_prob_lim)) THEN (0) ELSE (1)
test_5 = IF (event_occurance<5) OR (rand_5<(sa_prob_lim)) THEN (0) ELSE (1)
test_6 = IF (event_occurance<6) OR (rand_6<(sa_prob_lim)) THEN (0) ELSE (1)
test_7 = IF (event_occurance<1) OR (rand_1<(se_prob_lim)) OR (rand_1>50) THEN (0) ELSE
(1)
test_8 = IF (event_occurance<2) OR (rand_2<(se_prob_lim)) OR (rand_2>50) THEN (0) ELSE (1)
test_9 = IF (event_occurance<3) OR (rand_3<(se_prob_lim)) OR (rand_3>50) THEN (0) ELSE (1)
```

Not in a sector

```
Event_Switch = 0
```

Industry Problem Reporting and Other Agencies

☐ EPRI_Research_in_Progress(t) = EPRI_Research_in_Progress(t - dt) + (EPRI_res_initiation - EPRI_res_completion) * dt
INIT EPRI_Research_in_Progress = 0
INFLOWS:
EPRI_res_initiation = base_EPRI_res_projects*EFFidprobEPRI
OUTFLOWS:
EPRI_res_completion = EPRI_Research_in_Progress/time_to_comp_EPRI_res

☐ NRC_IN_in_Progress(t) = NRC_IN_in_Progress(t - dt) + (NRC_IN_initiation - NRC_IN_comp) * dt
INIT NRC_IN_in_Progress = 0
INFLOWS:
NRC_IN_initiation = frac_probs_need_IN*ident_probs_sent_to_NRC
OUTFLOWS:
NRC_IN_comp = NRC_IN_in_Progress/time_to_comp_IN

☐ VEN_Research_in_Progress(t) = VEN_Research_in_Progress(t - dt) + (VEN_res_initiation - VEN_res_completion) * dt
INIT VEN_Research_in_Progress = 0
INFLOWS:
VEN_res_initiation = base_VENDOR_res+ident_probs_sent_to_vendors
OUTFLOWS:
VEN_res_completion = VEN_Research_in_Progress/time_to_comp_VEN

☐ WANO_Reps_in_Progress(t) = WANO_Reps_in_Progress(t - dt) + (WANO_rep_init - WANO_rep_comp) * dt
INIT WANO_Reps_in_Progress = 0
INFLOWS:
WANO_rep_init = base_WANO_rep_production*EFFidprobWANO
OUTFLOWS:
WANO_rep_comp = WANO_Reps_in_Progress/time_to_comp_WANO_rep

○ base_EPRI_res_projects = 1
○ base_VENDOR_res = 1
○ base_WANO_rep_production = 2
○ frac_probs_need_IN = .5
○ frac_probs_sent_to_INPO = 1.0
○ frac_probs_sent_to_NRC = 1.0
○ frac_probs_sent_to_vendors = .1
○ ident_probs_sent_to_INPO = frac_probs_sent_to_INPO*identified_problems
○ ident_probs_sent_to_NRC = frac_probs_sent_to_NRC*identified_problems
○ ident_probs_sent_to_vendors = frac_probs_sent_to_vendors*identified_problems
○ time_to_comp_EPRI_res = 12
○ time_to_comp_IN = 4
○ time_to_comp_VEN = 28
○ time_to_comp_WANO_rep = 4

Not in a sector

identified_problems = unusual_event*probs_disc_per_unusual_event+site_alert*prob_disc_per__alert+site_emergencies*prob_disc_per_emergency+problems_from_major_event

EFFidprobEPRI = GRAPH(ident_prob_ratio)
(1.00, 1.04), (1.10, 1.10), (1.20, 1.10), (1.30, 1.10), (1.40, 1.12), (1.50, 1.16), (1.60, 1.28), (1.70, 1.62), (1.80, 2.37), (1.90, 3.32), (2.00, 5.00)

EFFidprobWANO = GRAPH(ident_prob_ratio)
(1.00, 1.00), (1.10, 1.01), (1.20, 1.02), (1.30, 1.02), (1.40, 1.03), (1.50, 1.04), (1.60, 1.05), (1.70, 1.09), (1.80, 1.16), (1.90, 1.30), (2.00, 1.49)

INPO

☐ INPO_Field_Invests_in_Progress(t) = INPO_Field_Invests_in_Progress(t - dt) + (field_invest_planned - INPO_rec_field_invest_completed) * dt
INIT INPO_Field_Invests_in_Progress = 3
INFLOWS:
field_invest_planned(i) = field_invest_planned(o) * CONVERSION MULTIPLIER
CONVERSION MULTIPLIER = 0.5
OUTFLOWS:
INPO_rec_field_invest_completed = INPO_Field_Invests_in_Progress/INPO_time_to_comp_fi

☐ INPO_Prob_Analysis_in_Progress(t) = INPO_Prob_Analysis_in_Progress(t - dt) + (INPO_prob_analysis_init - INPO_prob_analysis_comp) * dt
INIT INPO_Prob_Analysis_in_Progress = 15
INFLOWS:
INPO_prob_analysis_init = INPO_significant_problems
OUTFLOWS:
INPO_prob_analysis_comp = INPO_Prob_Analysis_in_Progress/INPO_time_to_analyze_probs

☐ Probs_Waiting_for_Screen_by_INPO(t) = Probs_Waiting_for_Screen_by_INPO(t - dt) + (problems_reported_to_INPO - INPO_probs_screened) * dt
INIT Probs_Waiting_for_Screen_by_INPO = 10
INFLOWS:
problems_reported_to_INPO = ident_probs_sent_to_INPO
OUTFLOWS:
INPO_probs_screened = Probs_Waiting_for_Screen_by_INPO/INPO_time_to_screen_event

☐ Recs_Waiting_for_Further_Investigation(t) = Recs_Waiting_for_Further_Investigation(t - dt) + (new_recs_to_inform - quick_SOER_responses - field_invest_planned) * dt
INIT Recs_Waiting_for_Further_Investigation = 5
INFLOWS:
new_recs_to_inform = INPO_prob_analysis_comp*frac_sig__probs_req_recs
OUTFLOWS:
quick_SOER_responses = Recs_Waiting_for_Further_Investigation*frac_recs_req_quick_SOER/INPO_time_to_produce_quick_SOER
field_invest_planned(o) = (1-frac_recs_req_quick_SOER)*Recs_Waiting_for_Further_Investigation/INPO_time_to_plan_fi

☐ SER_Writing_in_Progress(t) = SER_Writing_in_Progress(t - dt) + (SER_initiation - SER_reports) * dt
INIT SER_Writing_in_Progress = 20

INFLOWS:
SER_initiation = INPO_significant_problems
OUTFLOWS:

SER_reports = SER_Writing_in_Progress/time_to_produce_SER
fract_prob_req_SEN = .2
frac_recs_req_quick_SOER = .60
frac_sig_probs = .60
frac_sig__probs_req_reccs = .50
INPO_significant_problems = INPO_probs_screened*frac_sig_probs
INPO_time_to_analyze_probs = 2
INPO_time_to_comp_fi = 6
INPO_time_to_plan_fi = 2
INPO_time_to_produce_quick_SOER = 1
INPO_time_to_screen_event = 1
SEN_reports = INPO_significant_problems*fract_prob_req_SEN
SOER_reports = INPO_rec_field_invest_completed+quick_SOER_responses
time_to_produce_SER = 2

Not in a sector

ident_probs_sent_to_INPO = frac_probs_sent_to_INPO*identified_problems

Report Screen Process

Reps_Waiting_for_Screening(t) = Reps_Waiting_for_Screening(t - dt) + (Incoming_Reps - reports_screened - reps_abandoned) * dt
INIT Reps_Waiting_for_Screening = 70
INFLOWS:
Incoming_Reps = EPRI_res_completion+NRC_IN_comp+SEN_reports++VEN_res_completion+WANO_rep_comp+SER_reports+report_analyses_reopened
OUTFLOWS:
reports_screened = Reps_Waiting_for_Screening/adj_time_to_screen_reps
reps_abandoned = IF (info_eng_unavail_ratio>4) THEN frac_rep_abandoned*Reps_Waiting_for_Screening ELSE 0

SOERs_Waiting_for_Screening(t) = SOERs_Waiting_for_Screening(t - dt) + (Incoming_SOERs - SOER_screened) * dt
INIT SOERs_Waiting_for_Screening = 5
INFLOWS:
Incoming_SOERs = SOER_reports
OUTFLOWS:
SOER_screened = SOERs_Waiting_for_Screening/time_to_screen_SOER

adj_time_to_screen_reps = time_to_screen_reps*info_eng_unavail_ratio
app_reps = reports_screened*frac_reps_dtmd_app
app_reps_prev_anal = reports_screened*frac_reps_prev_analyzed
app_SOER = SOER_screened*frac_SOER_dtmd_app

concerns_from_app_SOER = app_SOER*concerns_per_SOER
concerns_per_SOER = 5
frac_reps_dtmd_app = 1-frac_reps_prev_analyzed
frac_reps_prev_analyzed = .3*EFF_DEF_RED_repeat_reps
frac_rep_abandoned = .4
frac_SOER_dtmd_app = .80
non_app_reps = reports_screened*(1-frac_reps_prev_analyzed-frac_reps_dtmd_app)
non_app_SOER = SOER_screened*(1-frac_SOER_dtmd_app)

time_to_screen_reps = 1
time_to_screen_SOER = dt

Not in a sector

EFF_DEF_RED_repeat_reps = { Place right hand side of equation here... }
EPRI_res_completion = EPRI_Research_in_Progress/time_to_comp_EPRI_res
info_eng_unavail_ratio = IF(TIME<1)OR Per_Outage=1THEN(1)ELSE(info_eng_WTB/(eng_info_rev_comp+1))
NRC_IN_comp = NRC_IN_in_Progress/time_to_comp_IN
report_analyses_reopened = { Place right hand side of equation here... }
SEN_reports = INPO_significant_problems*fract_prob_req_SEN

- SER_reports = SER_Writing_in_Progress/adj_time_to_produce_SER
- SOER_reports = INPO_rec_field_invest_completed+quick_SOER_responses
- VEN_res_completion = VEN_Research_in_Progress/time_to_comp_VEN
- WANO_rep_comp = WANO_Reps_in_Progress/time_to_comp_WANO_rep

IN-Plant Problem Screening

- Probs_Waiting_for_Screening(t) = Probs_Waiting_for_Screening(t - dt) + (new_incoming_problems - prob_screened_by_NWE - probs_not_screened_by_NWE) * dt
  INIT Probs_Waiting_for_Screening = 0
  INFLOWS:
    - new_incoming_problems = IF dfcts_discvrd_&_lost>0 THEN dfcts_discvrd_&_lost*problems_per_defect ELSE 0
  OUTFLOWS:
    - prob_screened_by_NWE = Probs_Waiting_for_Screening*frac_probs_screen_by_NWE/time_for_NWE_to_screen
    - probs_not_screened_by_NWE = Probs_Waiting_for_Screening*(1-frac_probs_screen_by_NWE)
- Prob_Screening_in_Progress(t) = Prob_Screening_in_Progress(t - dt) + (new_prob_screen - problem_screening_completion) * dt
  INIT Prob_Screening_in_Progress = 30
  INFLOWS:
    - new_prob_screen = probs_not_screened_by_NWE+prob_screened_by_NWE-quick_CA_to__prob_needed
  OUTFLOWS:
    - problem_screening_completion = Prob_Screening_in_Progress/adj_time_to_screen_problem

- adj_time_to_screen_problem = time_to_screen_problems*info_eng_unavail_ratio
- EFFincprobsNWE = SMTH1(new_incoming_problems,4,20)/new_incoming_problems
- frac_of_probs_req_eval = .75
- frac_probs_screen_by_NWE = .25*EFFincprobsNWE
- frac_prob_need_quick_CA = .25
- problems_per_defect = 1/50
- quick_CA_to__prob_needed = prob_screened_by_NWE*frac_prob_need_quick_CA
- significant_problems = problem_screening_completion*frac_of_probs_req_eval
- time_for_NWE_to_screen = dt
- time_to_screen_problems = 2

Not in a sector

- dfcts_discvrd_&_lost = IF TIME >52 THEN (dfcts_ID_frm_insp-dfcts_forgotten) ELSE 300
- info_eng_unavail_ratio = IF(TIME<1)OR Per_Outage=1THEN(1)ELSE(info_eng_WTB/(eng_info_rev_comp+1))

Evaluation Process

- Evals_Waiting_for_Validation(t) = Evals_Waiting_for_Validation(t - dt) + (eval_validation_init - evals_performed_correctly - evals_performed_incorrectly) * dt
  INIT Evals_Waiting_for_Validation = 45
  INFLOWS:
  - eval_validation_init = items_evaluated

  OUTFLOWS:
  - evals_performed_correctly = frac_correctly_eval*Evals_Waiting_for_Validation/adj_time_to_val_evals
  - evals_performed_incorrectly = evals_performed_correctly*((1-frac_correctly_eval)/frac_correctly_eval)
- Evaluations_in_Progress(t) = Evaluations_in_Progress(t - dt) + (new_item_evaluations - items_evaluated - evals_abandoned) * dt
  INIT Evaluations_in_Progress = 275
  INFLOWS:
  - new_item_evaluations = (app_reps+concerns_from_app_SOER)+significant_problems+evals_performed_incorrectly

  OUTFLOWS:
  - items_evaluated = Evaluations_in_Progress/adj_time_to_eval
  - evals_abandoned = IF (info_eng_unavail_ratio>eval_eng_unavail_lim) THEN (frac_evals_abandoned*Evaluations_in_Progress) ELSE 0
- adj_time_to_eval = time_to_eval*info_eng_unavail_ratio
- adj_time_to_val_evals = time_to_val_evals*info_mgr_unavail_ratio
- eval_eng_unavail_lim = 3
- frac_correctly_eval = .85*eff_OT_fatigue_eng
- frac_evals_abandoned = .10
- time_to_eval = 6
- time_to_val_evals = 1

Not In a sector

- app_reps = reports_screened*frac_reps_dmd_app
- concerns_from_app_SOER = app_SOER*concerns_per_SOER
- info_eng_unavail_ratio = IF(TIME<1)OR Per_Outage=1THEN(1)ELSE(info_eng_WTB/(eng_info_rev_comp+1))
- info_mgr_unavail_ratio = IF (TIME<.5) OR Per_Outage=1 THEN 1 ELSE (info_mgr_WTB/mgr_info_rev_comp+1)
- significant_problems = problem_screening_completion*frac_of_probs_req_eval
- eff_OT_fatigue_eng = GRAPH(avg_E_overtime)
  (0.00, 1.00), (2.22, 0.982), (4.44, 0.956), (6.67, 0.917), (8.89, 0.87), (11.1, 0.844), (13.3, 0.827), (15.6, 0.814), (17.8, 0.804), (20.0, 0.802)

Action Process

☐ CA_Waiting_for_Assignment(t) = CA_Waiting_for_Assignment(t - dt) + (new_CA_waiting - CA_assignment - CA_abandon) * dt
INIT CA_Waiting_for_Assignment = 35
INFLOWS:
new_CA_waiting = evals_performed_correctly*frac_of_evals_need_CA*(1+frac_evals_need_mult_CA)+quick_CA_to__prob_needed+CA_from_regs
OUTFLOWS:
CA_assignment = CA_Waiting_for_Assignment/adj_time_to_assign_CA
CA_abandon = IF (info_mgr_unavail_ratio>assign_mgr_unavail_lim) OR (info_eng_unavail_ratio>assign_eng_unavail_lim) THEN CA_Waiting_for_Assignment*frac_CA_abandon ELSE 0

☐ Mod_CA_in_Progress(t) = Mod_CA_in_Progress(t - dt) + (new_mod_CA - mod_CA_planned) * dt
INIT Mod_CA_in_Progress = 60

INFLOWS:
new_mod_CA = CA_assignment*frac_CA_mod
OUTFLOWS:
mod_CA_planned = Mod_CA_in_Progress/adj_time_to_plan_mod_CA

☐ Proc_CA_Waiting_for_Val(t) = Proc_CA_Waiting_for_Val(t - dt) + (proc_CA__completed - proc_CA_validated - proc_CA_incorrect) * dt
INIT Proc_CA_Waiting_for_Val = 25
INFLOWS:
proc_CA__completed = Proc_CA__in_Progress/adj_time_to_comp_proc_CA
OUTFLOWS:
proc_CA_validated = frac_proc_CA_correct*Proc_CA_Waiting_for_Val/adj_time_to_val_proc_CA
proc_CA_incorrect = proc_CA_validated*((1-frac_proc_CA_correct)/frac_proc_CA_correct)

☐ Proc_CA__in_Progress(t) = Proc_CA__in_Progress(t - dt) + (proc_CA - proc_CA__completed) * dt
INIT Proc_CA__in_Progress = 200

INFLOWS:
proc_CA = (CA_assignment*frac_CA_proc+proc_CA_incorrect)*EFF_mainOT_info
OUTFLOWS:
proc_CA__completed = Proc_CA__in_Progress/adj_time_to_comp_proc_CA

☐ Train_CA_in_Progress(t) = Train_CA_in_Progress(t - dt) + (train_CA - train_CA__completed) * dt
INIT Train_CA_in_Progress = 200

INFLOWS:
train_CA = (CA_assignment*frac_CA_train+train_CA_incorrect)*EFF_mainOT_info
OUTFLOWS:
train_CA__completed = Train_CA_in_Progress/adj_time_to_comp_train_CA

☐ Train_CA_Waiting_for_Val(t) = Train_CA_Waiting_for_Val(t - dt) + (train_CA__completed - train_CA_validated - train_CA_incorrect) * dt

INIT Train_CA_Waiting_for_Val = 15

INFLOWS:

- train_CA__completed = Train_CA_in_Progress/adj_time_to_comp_train_CA

OUTFLOWS:

- train_CA_validated = frac_train_CA_correct*Train_CA_Waiting_for_Val/adj_time_to_val_train_CA
- train_CA_incorrect = train_CA_validated*((1-frac_train_CA_correct)/frac_train_CA_correct)

○ adj_time_to_assign_CA = time_to_assign_CA*info_mgr_unavail_ratio
○ adj_time_to_comp_proc_CA = time_to_comp_proc_CA*info_eng_unavail_ratio
○ adj_time_to_comp_train_CA = time_to_comp_train_CA*info_eng_unavail_ratio
○ adj_time_to_plan_mod_CA = time_to_plan_mod_CA*info_eng_unavail_ratio
○ adj_time_to_val_proc_CA = time_to_val_proc_CA*info_mgr_unavail_ratio
○ adj_time_to_val_train_CA = time_to_val_train_CA*info_mgr_unavail_ratio
○ assign_eng_unavail_lim = 3
○ assign_mgr_unavail_lim = 3
○ frac_CA_abandon = .2
○ frac_CA_mod = .2
○ frac_CA_proc = .6
○ frac_CA_train = .2
○ frac_evals_need_mult_CA = .2
○ frac_of_evals_need_CA = .75
○ frac_proc_CA_correct = .90*eff_OT_fatigue_eng
○ frac_train_CA_correct = .90*eff_OT_fatigue_eng
○ time_to_assign_CA = 1
○ time_to_comp_proc_CA = 10
○ time_to_comp_train_CA = 20
○ time_to_plan_mod_CA = 12
○ time_to_val_proc_CA = 1
○ time_to_val_train_CA = 2

Not in a sector

(?) CA_from_regs = new_reg_evals_completed*probs_to_correct_per_reg
(?) EFF_mainOT_info = { Place right hand side of equation here... }
(?) evals_performed_correctly = frac_correctly_eval*Evals_Waiting_for_Validation/adj_time_to_val_evals

(?) info_eng_unavail_ratio = IF(TIME<1)OR Per_Outage=1THEN(1)ELSE(info_eng_WTB/(eng_info_rev_comp+1))
(?) info_mgr_unavail_ratio = IF (TIME<.5) OR Per_Outage=1 THEN 1 ELSE (info_mgr_WTB/mgr_info_rev_comp+1)
(?) quick_CA_to__prob_needed = prob_screened_by_NWE*frac_prob_need_quick_CA

⑦ eff_OT_fatigue_eng = GRAPH(ave_E_overtime)
(0.00, 1.00), (2.22, 0.982), (4.44, 0.956), (6.67, 0.917), (8.89, 0.87), (11.1, 0.844), (13.3, 0.827), (15.6, 0.814), (17.8, 0.804), (20.0, 0.802)

Interactions with NRC

☐ NEI_Abandon_Effort_in_Progress(t) = NEI_Abandon_Effort_in_Progress(t - dt) + (NEI_effort_to_aband_reg - regulation_abandoned_effort_comp) * dt
INIT NEI_Abandon_Effort_in_Progress = 0
INFLOWS:
NEI_effort_to_aband_reg = regs_des_aband
OUTFLOWS:
regulation_abandoned_effort_comp = NEI_Abandon_Effort_in_Progress/time_to_influence_NRC

☐ Regulations_Under_Technical_Review(t) = Regulations_Under_Technical_Review(t - dt) + (tech_review_of_new_regs_init - regs_des_aband - reg_reviews_completed) * dt
INIT Regulations_Under_Technical_Review = .2
INFLOWS:
tech_review_of_new_regs_init = reg_reviews_assigned
OUTFLOWS:
regs_des_aband = frac_regs_des_aband*Regulations_Under_Technical_Review/(time_to_comp_reg_rev/4)

reg_reviews_completed = Regulations_Under_Technical_Review/adj_time_to_comp_reg_review

☐ Reg_Eval_in_Progress(t) = Reg_Eval_In_Progress(t - dt) + (new_regs_to_implement - new_reg_evals_completed) * dt
INIT Reg_Eval_In_Progress = 0
INFLOWS:
new_regs_to_implement = enacting_regulation
OUTFLOWS:
new_reg_evals_completed = Reg_Eval_In_Progress/adj_time_to_comp_reg_eval

☐ Reg_Reviews_Waiting_for_Assign(t) = Reg_Reviews_Waiting_for_Assign(t - dt) + (new_regs_to_review - reg_reviews_assigned) * dt
INIT Reg_Reviews_Waiting_for_Assign = 0
INFLOWS:
new_regs_to_review = frac_of_regs_to_review*initiating_regulation
OUTFLOWS:
reg_reviews_assigned = Reg_Reviews_Waiting_for_Assign/adj_time_to_assign_reg_review

○ adj_time_to_assign_reg_review = time_to_assign_reg_review*info_mgr_unavail_ratio
○ adj_time_to_comp_reg_eval = EFFregrev*info_eng_unavail_ratio*time_to_comp_reg_eval
○ adj_time_to_comp_reg_review = time_to_comp_reg_rev*info_eng_unavail_ratio
○ CA_from_regs = new_reg_evals_completed*CA_per_reg
○ CA_per_reg = 25
○ frac_of_regs_to_review = .80
○ frac_regs_abandoned = 1.00
○ frac_regs_des_aband = 0

regulations_abandoned_from_NEI_effort = frac_regs_abandoned*regulation_abandoned_effort_comp

time_to_assign_reg_review = 1

time_to_comp_reg_eval = 6

time_to_comp_reg_rev = 12

time_to_influence_NRC = 12

EFFregrev = GRAPH(frac_of_regs_to_review)
(0.00, 3.50), (0.1, 3.33), (0.2, 3.10), (0.3, 2.79), (0.4, 2.31), (0.5, 1.89), (0.6, 1.53), (0.7, 1.31), (0.8, 1.18), (0.9, 1.09), (1, 1.00)

EFF_reg_aband_eng_and_mgr = GRAPH(IF Regulations_Under_Technical_Review>.15 AND TIME>104 THEN frac_regs_des_aband ELSE 0)
(0.00, 1.00), (0.1, 0.875), (0.2, 0.725), (0.3, 0.405), (0.4, 0.24), (0.5, 0.1), (0.6, 0.025), (0.7, 0.015), (0.8, 0.005), (0.9, 0.00), (1, 0.005)

Not in a sector

enacting_regulation = NRC_Regulations_In_Development/time_to_enact_regulation

info_eng_unavail_ratio = IF(TIME<1)OR Per_Outage=1THEN(1)ELSE(info_eng_WTB/(eng_info_rev_comp+1))

info_mgr_unavail_ratio = IF (TIME<.5) OR Per_Outage=1 THEN 1 ELSE (info_mgr_WTB/mgr_info_rev_comp+1)

initiating_regulation = Report_Ratio*Ave_Regulations_Sought_per_Report*Reports_Completed

Information Learning Curve

☐ Cumulative_Info_CA_Performed(t) = Cumulative_Info_CA_Performed(t - dt) + (info_CA_performed) * dt

INIT Cumulative_Info_CA_Performed = 30*52*5

INFLOWS:

info_CA_performed = proc_CA_validated+train_CA_validated

☐ DEF_RED(t) = DEF_RED(t - dt) + (def_red_rate_decreasing) * dt

INIT DEF_RED = .95

INFLOWS:

def_red_rate_decreasing = IF(TIME>5)THEN(-DEF_RED*fractional_info_CA_completion*modified_info_lc_frac) ELSE (0)

○ fractional_info_CA_completion = info_CA_performed/Cumulative_Info_CA_Performed

○ info_lc_frac = .025

○ modified_info_lc_frac = -LOGN(1-(info_lc_frac*Training_Hours))/LOGN(2)

⊘ EFF_DEF_RED_repeat_reps = GRAPH(DEF_RED)
(0.6, 1.50), (0.64, 1.48), (0.68, 1.47), (0.72, 1.44), (0.76, 1.38), (0.8, 1.21), (0.84, 1.13), (0.88, 1.06), (0.92, 1.02), (0.96, 1.00), (1.00, 1.00)

Not in a sector

proc_CA_validated = frac_proc_CA_correct*Proc_CA_Waiting_for_Val/adj_time_to_val_proc_CA

Training_Hours = Frac_Bud_Trng*standard_hours

train_CA_validated = frac_train_CA_correct*Train_CA_Waiting_for_Val/adj_time_to_val_train_CA

Information Labor Calc

☐ info_eng_WTB(t) = info_eng_WTB(t - dt) + (chg_info_eng_WTB) * dt
INIT info_eng_WTB = 0
INFLOWS:
chg_info_eng_WTB = info_eng_work_des-info_eng_WTB

☐ info_mgr_WTB(t) = info_mgr_WTB(t - dt) + (chg_info_mgr_WTB) * dt
INIT info_mgr_WTB = 0
INFLOWS:
chg_info_mgr_WTB = info_mgr_work_des-info_mgr_WTB

○ info_eng_unavail_ratio = IF(TIME<1)THEN(1)ELSE((info_eng_WTB+1)/(eng_info_rev_comp+1))

○ info_eng_work_des = (Mod_CA_in_Progress+Proc_CA__in_Progress+Reps_Waiting_for_Screening+Evaluations_in_Progress+SOERs_Waiting_for_Screening+Train_CA_in_Progress+Prob_Screening_in_Progress+NWE+(Regulations_Under_Technical_Review+Reg_Eval_In_Progress)*info_eng_WTB_per_reg*info_eng_WTB_per_eng_per_week)

○ info_eng_WTB_per_eng_per_week = 16

○ info_eng_WTB_per_reg = 25

○ info_mgr_unavail_ratio = IF (TIME<.5) THEN 1 ELSE ((info_mgr_WTB+1)/mgr_info_rev_comp+1)

○ info_mgr_work_des = (CA_Waiting_for_Assignment+Evals_Waiting_for_Validation+Proc_CA_Waiting_for_Val+Train_CA_Waiting_for_Val+Reg_Reviews_Waiting_for_Assign*info_mgr_WTB_per_reg*info_mgr_WTB_per_mgr_per_week)

○ info_mgr_WTB_per_mgr_per_week = 10

○ info_mgr_WTB_per_reg = 10

Not in a sector

☐ CA_Waiting_for_Assignment(t) = CA_Waiting_for_Assignment(t - dt)
INIT CA_Waiting_for_Assignment = 35

☐ Evals_Waiting_for_Validation(t) = Evals_Waiting_for_Validation(t - dt)
INIT Evals_Waiting_for_Validation = 45

☐ Evaluations_in_Progress(t) = Evaluations_in_Progress(t - dt)
INIT Evaluations_in_Progress = 275

☐ Mod_CA_in_Progress(t) = Mod_CA_in_Progress(t - dt)
INIT Mod_CA_in_Progress = 60

☐ Prob_Screening_in_Progress(t) = Prob_Screening_in_Progress(t - dt)
INIT Prob_Screening_in_Progress = 30

☐ Proc_CA_Waiting_for_Val(t) = Proc_CA_Waiting_for_Val(t - dt)
INIT Proc_CA_Waiting_for_Val = 25

☐ Proc_CA__in_Progress(t) = Proc_CA__in_Progress(t - dt)
INIT Proc_CA__in_Progress = 200

☐ Regulations_Under_Technical_Review(t) = Regulations_Under_Technical_Review(t - dt)
INIT Regulations_Under_Technical_Review = .2

☐ Reg_Eval_In_Progress(t) = Reg_Eval_In_Progress(t - dt)
INIT Reg_Eval_In_Progress = 0

☐ Reg_Reviews_Waiting_for_Assign(t) = Reg_Reviews_Waiting_for_Assign(t - dt)
INIT Reg_Reviews_Waiting_for_Assign = 0

☐ Reps_Waiting_for_Screening(t) = Reps_Waiting_for_Screening(t - dt)
INIT Reps_Waiting_for_Screening = 70

☐ SOERs_Waiting_for_Screening(t) = SOERs_Waiting_for_Screening(t - dt)
INIT SOERs_Waiting_for_Screening = 5

☐ Train_CA_in_Progress(t) = Train_CA_in_Progress(t - dt)
INIT Train_CA_in_Progress = 200

☐ Train_CA_Waiting_for_Val(t) = Train_CA_Waiting_for_Val(t - dt)
INIT Train_CA_Waiting_for_Val = 15

eng_info_rev_comp =
eng_saf_info_rev_avail*Human_Effs_on_Work_Comp_Eng*EFF_Estaff_exp*(1+target_frac_eng_overtime*eff_info_wkd_OT)*eff_prod_pres_on_E_OT

mgr_info_rev_comp =
mgr_info_rev_avail*Human_Effs_on_Work_Comp_Mgr*Eff_Mgt_staff_exp*(1+target_frac_Mgt_OT*eff_mgr_mnt_wkd_OT)*eff_prod_pres_on_Mgt_OT

NWE = IF(prob_srcreened_by_NWE>0) THEN (1) ELSE 0

Info Salp Effect

☐ Cumulative_Reports_Available(t) = Cumulative_Reports_Available(t - dt) + (new_reps) * dt
INIT Cumulative_Reports_Available = 1
INFLOWS:
new_reps = Incoming_Reps++Incoming_SOERs+new_incoming_problems

☐ Total_Report_Analyses_Abandoned(t) = Total_Report_Analyses_Abandoned(t - dt) + (report_analyses_abandoned - report__analyses_reopened) * dt
INIT Total_Report_Analyses_Abandoned = 0
INFLOWS:
report_analyses_abandoned = CA_abandon+evals_abedoned+reps_abandoned
OUTFLOWS:
report__analyses_reopened = EFF_SALP_info*Total_Report_Analyses_Abandoned

○ report_analysis_ratio =
(Cumulative_Reports_Available-Total_Report_Analyses_Abandoned)/Cumulative_Reports_Available

Not in a sector

CA_abandon = IF (info_mgr_unavail_ratio>assign_man_unavil_lim) OR (info_eng_unavail_ratio>assign_eng_unavail_lim) THEN CA_Waiting_for_Assignment*frac_CA_abandon ELSE 0

evals_abedoned = IF (info_eng_unavail_ratio>eval_eng_unavail_lim) THEN (frac_evals_abandoned*Evaluations_in_Progress) ELSE 0

Incoming_Reps =
EPRI_res_completion+NRC_IN_comp+SEN_reports++VEN_res_completion+WANO_rep_comp+SER_reports+report__analyses_reopened

Incoming_SOERs = SOER_reports

new_incoming_problems = IF dfcts_discvrd_&_lost>0 THEN dfcts_discvrd_&_lost*problems_per_defect ELSE 0

reps_abandoned = IF (info_eng_unavail_ratio>4) THEN frac_rep_abandoned*Reps_Waiting_for_Screening ELSE 0

EFF_SALP_info = GRAPH(SALP)
(1.00, 0.00), (1.50, 0.00), (2.00, 0.00), (2.50, 0.00), (3.00, 0.05), (3.50, 0.1), (4.00, 0.1)

APPENDIX B
Glossary of Variables in Information Sector

adj time to *	The variables that begin with 'adj time to' are the time delays in the utility's information processing adjusted for the availability of information engineers.
app reps	Reports that are applicable to the utility. Applicable means they could have some safety or performance impact on the plant.
app reps prev anal	Reports that are applicable to the utility but have been previously analyzed.
app SOER	SOERs that are applicable to the utility. Applicable means they could have some safety or performance impact on the plant.
assign eng unavail lim	Highest value of info eng unavail ratio allowed until an information manager drops evaluations before corrective actions initiation. If the engineers are overloaded, the manager serves to reduce their workload by abandoning reports.
assign mgr unavail lim	Highest value of info mgr unavail ratio allowed until an information manager drops evaluations before corrective actions initiation. If the mangers are overloaded, the manager serves to reduce workload by abandoning reports.
base EPRI res projects	Base rate that EPRI initiates research projects.
base prob sa	Probability of an event occurrence being a site alert.
base prob se	Probability of an event occurrence being a site emergency.
base VENDOR res	Base rate that vendors initiate research project.
base WANO rep production	Base rate that WANO produces reports of international significance.
CA abandon	Corrective actions abandoned because of high information staff workloads.
CA assignment	Corrective actions assigned to procedure, training, and modifications.
CA from regs	Corrective actions that come from regulations.
CA per reg	Corrective actions per regulation.
CA Waiting for Assignment	Corrective actions waiting to be assigned to an information engineer by a manager.
chg info eng WTB	Change in total information engineer work to be done.
chg info mgr WTB	Change in total information manager work to be done.
concerns from app SOER	Concerns from applicable SOERs.
concerns per SOER	Concerns per SOER.
Cumulative Info CA Performed	Cumulative number of information corrective actions performed.
DEF RED	Multiplier on all defects to reduce the number occurring. Serves to reduce defect causes from information use.
def red rate decreasing	Amount the DEF RED decreases from corrective actions.
EFF DEF RED repeat reps	Effect of defect reduction on repeat reports. As the DEF RED multiplier increases, more reports that the utility uses have been seen previously.
EFF reg aband eng and man	Effect of regulation abandonment on engineers and managers. If the utility wants the NRC to abandon regulations, the effort reduces the number of engineers and managers available for work.
EFF sitealandemerg NRCIns	Effect of site alerts and emergencies on NRC inspections. If a large number of site alerts occur or a site emergency occurs, the NRC increases inspections.
EFFidprobEPRI	Effect of identified problems on EPRI. If the number of identified problems in the current week goes up compared to the past weeks, EPRI increases its research.

EFFidprobWANO	Effect of identified problems on WANO. If the number of identified problems in the current week goes up compared to the past weeks, WANO increases the number of reports it produces.
EFFincprobsNWE	Effect of incoming problems on NWE. This decreases the fraction of problems the NWE is able to screen, if a large amount are found. This way the NWE is limited in the number of problems it can screen.
EFFregrev	Effect of regulation review on the ability of information engineers to analyze regulations.
EPRI res completion	EPRI completion of research.
EPRI res initiation	EPRI initiation of research.
EPRI Research in Progress	Research at EPRI that is on-going.
eval eng unavail lim	Highest value of info eng unavail ratio allowed until an information engineer drops evaluations. If they engineers are overloaded, they reduce their workload by dropping reports.
eval validation init	Evaluation validation initiation.
evals abandoned	Evaluations abandoned because of high information staff workloads.
evals performed correctly	Evaluations performed correctly by engineers.
evals performed incorrectly	Evaluations performed incorrectly by engineers.
Evals Waiting for Validation	Evaluations waiting to be validated by an information manager.
Evaluations in Progress	Evaluations of information reports that are in-progress.
event occurrences	The number of events (not yet screened for event type) occurring at other nuclear power plants.
event pool reset	Resets number of outside plant events per year.
Event Processing	Sub-model to process event occurrences to determine if they are: unusual events, site alerts or site emergencies.
event switch	Switch to turn on major event (TMI-like) at week 156 in the model.
events per year	Number of event occurrences that will occur per year.
field invest planned	Field investigations planned by INPO.
frac CA abandon	Fraction of corruptive actions that are abandoned by information managers in the assignment limits for manpower availability are reached.
frac CA mod	Frac of corrective actions that are modifications
frac CA proc	Fraction of corrective actions that are procedural.
frac CA train	Fraction of corrective actions that are training.
frac correctly eval	Fraction of evaluations that are performed correctly.
frac evals abandoned	Fraction of evaluations that are abandoned if the information engineers are too busy.
frac evals need CA	Fraction of evaluations that require corrective actions in the plant.
frac evals need mult CA	Fraction of evaluations that need multiple corrective actions.
frac of probs req eval	Fraction of problems in reports that require further evaluation.
frac prob need quick CA	Fraction of problems identified in the plant (from defects) that warrant quick corrective actions (evaluation is skipped).
frac prob req. SEN	Fraction of problems at INPO that require SENs.
frac prob screen by NWE	Frac of problems in the plant screened by the NWE (Nuclear Watch Engineer).
frac probs need IN	Fraction of problems identified that need Information Notifications from the NRC.
frac probs sent to INPO	Fraction of identified problems sent to INPO for analysis.
frac probs sent to NRC	Fraction of identified problems sent to NRC for analysis.
frac probs sent to vendors	Fraction of identified problems sent to vendors to initiate research
frac proc CA correct	Fraction of procedure corrective actions that are correct.

frac recs req quick SOER	Fraction of recommendations from INPO that are published in quick SOERs.
frac reg abandoned	Fraction of regulations abandoned from NEI and the utility's effort.
frac regs des aband	Fraction of regulations desired abandoned by the utility.
frac regs to review	Fraction of regulations that are reviewed in the information sector.
frac rep abandoned	Fraction of reports that are abandoned before they are screened, if information engineers are not available
frac reps dtmd app	Fraction of reports determined applicable to the plant.
frac reps prev analyzed	Fraction of reports previously analyzed in the plant.
frac sig probs	Fraction of problems at INPO that are significant to the industry.
frac sig probs req reccs	Fraction of significant problems at INPO that require INPO recommendations.
frac SOER dtmd app	Fraction of SOER determined applicable to the plant.
frac train CA correct	Fraction of training corrective actions that are performed correctly.
fractional info CA completion	Fractional information corrective action completion. Ratio of current level of corrective action completion to cumulative corrective actions.
ident prob ratio	Identified problem ratio. Ratio of current identified problems (in the industry) to a smoothed level over the time horizon to compare industry problems.
ident probs sent to INPO	Identified problems sent to INPO for analysis.
ident probs sent to NRC	Identified problems to the NRC for analysis.
ident probs sent to vendors	Identified problems sent to vendors for research
identified problems	Number of problems identified at the plants from the various irregular even occurrences.
Incoming Reps	Various reports coming into the utility for screening.
Incoming SOERs	SOER's coming into the utility for screening.
info CA performed	Total number of information corrective actions performed.
info eng unavail ratio	Information engineer unavailability ratio. Ratio of work to be done in the information sector to work available to be done by information engineers in the plant.
info eng work des	Information engineer work desired. Work desired to be completed by information engineers.
info eng WTB	Information work to be done.
info eng WTB per eng per week	Information engineer work to be done per engineer per week. Amount of work an information engineer can do in one week.
info eng WTB per reg	Information engineer work to be done per regulation. Amount of work to be done from an NRC regulation.
info lc frac	Information learning curve fraction. Fractional reduction in defect causes for a doubling of corrective actions.
info mgr unavail ratio	Information manager unavailability ratio. Ratio of work to be done in the information sector to work available to be done by information managers in the plant.
info mgr work des	Information engineer work desired. Work desired to be completed by information managers.
info mgr WTB	Information work to be done.
info mgr WTB per mgr per week	Information manager work to be done per manager per week. Amount of work an information manager can do in one week.
info mgr WTB per reg	Information manager work to be done per regulation. Amount of work to be done from an NRC regulation.
INPO prob analysis comp	INPO problem analysis completion.
INPO prob analysis init	INPO Problem analysis initiation.

INPO probs screened	INPO problem screening completion.
INPO rec field invest completed	INPO recommendation field investigations completed.
INPO significant problems	Problems that are significant at INPO.
INPO time to analyze probs	Time it takes INPO to analyze problems.
INPO time to comp fi	Time it takes INPO to complete field investigations.
INPO time to produce quick SOER	Time it takes INPO to publish a quick SOER.
INPO time to produce SER	Time it takes INPO to produce a SER.
INPO time to screen event	Time it takes INPO to screen an event.
item evaluated	Items evaluated in the information sector.
Mod CA in Progress	Modification corrective actions in progress.
mod CA planned	Modification corrective actions planned.
modified info lc frac	Modified information learning curve fractions. Modified lc frac for use in the learning curve, and takes training into account.
NEI Abandon Effort in Progress	NEI regulation abandon effort that is in progress. Represents the number of regulations that NEI is trying to get the NRC to abandon.
NEI effort to aband reg	NEI effort to abandon regulations at the NRC.
new CA waiting	New corrective actions waiting for assignment by a manager.
new incoming problems	New incoming problems discovered from plant defects.
new item evaluations	New items to evaluation after being screened.
new mod CA	New modification corrective actions initiated
new prob screen	New in-plant problems to be screened by information engineers.
new recs to inform	New INPO recommendations to inform utilities.
new reg evals completed	New regulation evaluations completed.
new regs to implement	New regulations to implement at the plant.
new regs to review	New regulations to undergo regulation review.
non app reps	Reports that are non applicable to the plant.
non app SOER	SOERs that not applicable to the plant.
NRC IN comp	NRC Information Notification completion.
NRC IN in Progress	NRC Information Notifications being written.
NRC IN initiation	NRC Information Notification initiation.
prob not screened by NWE	In-plant problems not screened by the NWE.
prob screened by NWE	In-plant problems screened by the NWE.
Prob Screening in Progress	In-plant problem screening by the information engineers in progress.
problem screening completion	In-plant problem screening completion by information engineers.
problems per defect	Number of plant problems identified per defects.
problems reported to INPO	Problems identified that are reported to INPO.
probs disc per alert	Number of problems discovered per alert.
probs disc per emergency	Number of problems discovered per emergency
probs disc per unusual event	Number of problems discovered from an unusual event
probs from major event	Problems identified from a major event/
Probs Waiting for Screening	In-plant problems waiting to be screened by the NWE or other information engineers.
proc CA	Procedure corrective action initiation.
proc CA completed	Procedure corrective actions completed.
Proc CA In Progress	Procedure corrective actions in progress.
proc CA incorrect	Procedure corrective actions performed incorrectly.
proc CA validated	Procedure corrective actions validated by a manager.
Proc CA Waiting for Val	Procedure corrective actions waiting to be validated for correctness.

quick CA to prob needed	Quick corrective actions to problems needed
quick SOER responses	Quick SOER responses to INPO recommendations.
rand for num events	Random number to determine the number of events that occurred.
rand seed	Seed value for random numbers.
RANDOM	Ithink® to generate random numbers.
reg des aband	Regulations desired abandoned by the utility.
Reg Eval in Progress	Regulation evaluations in progress at the plant/
reg reviews assigned	Regulation reviews assigned. by information engineers.
reg reviews completed	Regulation reviews completed by information engineers.
Reg Reviews Waiting for Asssign	Regulations waiting to be assigned to technical groups at the plant.
regs des aband	Regulations desired abandoned by the utility.
regulations abandoned from NEI effort	Regulations abandoned before they reach the books at the NRC. Abandoned because of NEI's effort.
Regulations Under Technical Review	Regulations under technical review at the plant.
reports screened	Reports screened by information engineers.
reps abandoned	Reports abandoned before they are screened because of engineer workload.
Reps Waiting for Screening	Reports waiting to be screened at the plant.
SEN reports	SEN reports produced by INPO.
SER initiation	INPO initiation of SER production.
SER reports	INPO completion of SER production.
significant problems	Problems determined to significant to the industry by INPO.
site alerts	Site alert occurrence at another plant.
site emergencies	Site emergency occurrence at another plant.
SMTH1	Ithink® function that exponentially smooths the variable. Produces a first order exponential smooth of the input variable over the time specified.
SOER reports	SOER reports produced by INPO.
SOER Screened	SOER screened by the utility.
SOERs Waiting for Screening	SOERs waiting to be screened by information engineers
tech review of regs init	Initiation of technical reviews of NRC regulation in development
time for NWE to screen	Time for NWE to screen problems in the plant.
time horizon to comp ind probs	Time horizon that identified problems are remembered in the industry
time to assign CA	Time to assign corrective actions, not adjusted for engineer availability
time to assign review	Time to assign regulation reviews, not adjusted for manager availability
time to comp proc CA	Time to complete procedure corrective actions, not adjusted for engineer availability
time to comp reg rev	Time to complete regulation reviews, not adjusted for engineer availability
time to comp train CA	Time to complete training corrective actions, not adjusted for engineer availability
time to eval	Time to perform report evaluations, not adjusted for engineer availability
time to influence NRC	Time to influence NRC to abandon regulations, not adjusted for engineer availability
time to plan mod CA	Time to plan modification corrective actions, not adjusted for engineer availability

time to screen problems	Time to screen in-plant problems, not adjusted for engineer availability.
time to screen reps	Time to screen reports, not adjusted for engineer availability.
time to screen SOER	Time to screen SOER's.
time to val eval	Time to validate evaluations, not adjusted for manager availability.
time to val proc CA	Time to validate procedure corrective actions, not adjusted for manager availability.
time to val train CA	Time to validate training corrective actions, not adjusted for manager availability
train CA	Training corrective actions initiated.
train CA completed	Training corrective actions completed by information engineers.
Train CA in Progress	Training corrective actions under development, not adjusted for engineer availability.
train CA incorrect	Training corrective actions performed incorrect by engineers.
train CA validated	Training corrective actions performed correctly.
Train CA Waiting for Val	Training corrective actions waiting for validation.
unusual event	Unusual event occurrence at another plant.
VEN res completion	Vendor completion of research.
VEN res initiation	Vendor initiation of research.
VEN Research in Progress	Vendor research in progress.
WANO rep comp	WANO report completion.
WANO rep init	WANO initiation of reports.
WANO Reps in Progress	WANO reports being written.

APPENDIX C

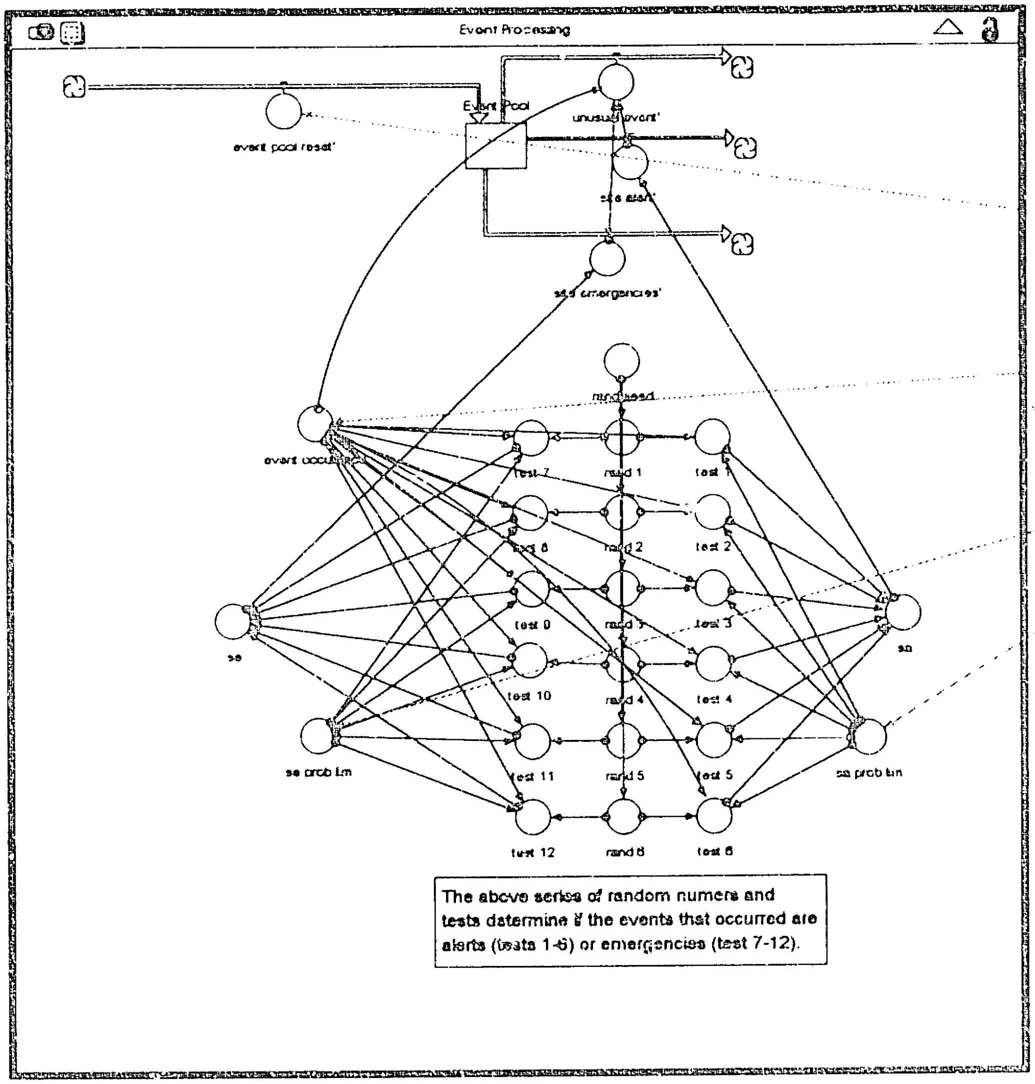

Figure C.1: Ithink® Diagram
Event Processing Sub-Model

Figure B-1 is the Ithink® representation of the Event Processing sub-model in the Industry Event sub-sector of the information model. This sub-model produces the different types of event occurrences in the industry based on the probabilities that they will occur. The complicated array of converters in the figure determines and tests random numbers to individually check each event to determine what type it is.