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System Simulation of a Management of Change process in a North Slope Oil Exploration Facility

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ABSTRACT

Our ability to manage the integrity of our facilities is directly related to our ability to manage change. Management of Change as a component of PSM has been part of the processing industry since 1994, yet in that time very little if any improvement has been observed (Moore, Acutech) in the overall safety performance at facilities. This study asserts that the reason for this lack of performance is that the MoC process is not managed but rather it is just used.

The ability of an organization to leverage change to their advantage and to minimize the risks involved with implementing change, at any level, is dependant on the organizational structure and tools put into place – it is dependant on the management system and the effectiveness of that system. A management system can be defined as an approach whereby a series of components or steps are put together to solve a problem or make an improvement in internal efficiency and external effectiveness. The Management of Change process for a major North Slope Oil Production facility was reviewed against the five components of a management system - Scope, Process, Organization, Performance Measurement and Feedback.

From this review a system simulation was developed using the iThink simulation language to model the MoC process. Through this simulation we were able to mimic the existing process in terms of delays and backlogs with the goal of not only understanding the process, but also understanding the impact a change in workload or the availability of technical reviewers would have on its performance.

Management of Change should be considered a tool not an obstacle to overcome and using the simulation process we are able to start managing the Management of Change system and then managing the integrity of our facilities.

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1.0 Introduction

Our ability to ensure the integrity of our production facilities is directly related to our ability to manage change. There is much at stake here; the North Slope oil fields account for 16% of the nation's oil production and are the largest oil production fields in North America. The continued production, the continued renewal of licenses to operate, as well as the opportunity to continue exploration, will depend on how well changes are managed at the facilities.

The purpose of this study is to examine (from a systems perspective) the current Management of Change (MoC) process in place at an operating facility on the North Slope. From this information a systems simulation will be developed that will mimic the existing MoC process allowing "management" to perform what-if analyses to determine strategies to enhance performance. It is in the best interest of the operating fields to make changes and improvements in their operations as the field conditions change, both from an operational efficiency and from a safety point of view. If we can look at improving the process of management systems (and in particular MoC) through a systems approach, then the objective of this work - the assurance of the integrity of the facility - will have been met.

Management of Change at its surface would seem to be no more than classic change control used by project managers for many years. But it is much more than simple change control; the stakes are much higher and there is a need for a more sophisticated approach. As Albert Einstein has said:

> *The world we have made as a result of the level of thinking we have done thus far creates problems we cannot solve at the same level of thinking at which we created them.*

This report will identify those new levels of thinking and in so doing point the way to a more efficient and safer operation of the North Slope Oil Fields.

Located at latitude 70 degrees north, 250 miles inside the Arctic Circle (see Figure 1), the North Slope oilfields, the largest oilfields in North America, have been producing crude oil for over 20 years. At its peak production the North Slope oil fields accounted for nearly 25% of the total United States oil production. Although in their twelfth year of decline they still account for 16% of U.S. oil production (BP World Energy Statistics).

Connected to the port of Valdez by the 800 mile Trans-Alaskan Pipeline, Prudhoe Bay, the largest and the oldest of the North Slope oil fields came on stream June 20, 1977, producing more than 1.5 million barrels of oil and gas liquid per day for more than a decade. Production began to decline in 1988 and by early 1999 the field was producing approximately 680,000 barrels of oil per day.

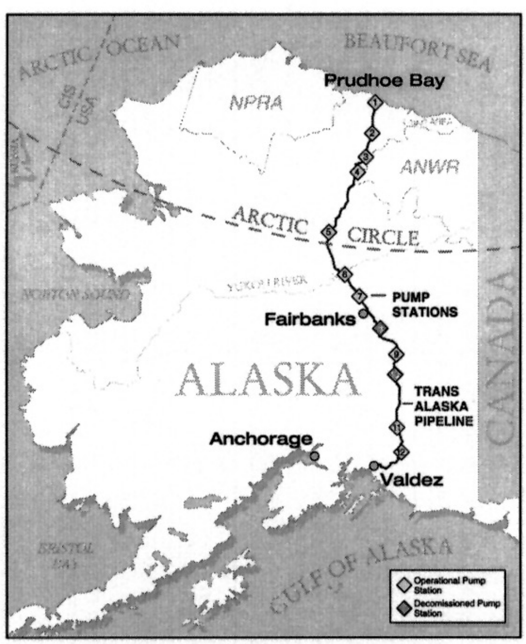


Figure 1 – Location of Prudhoe Bay and the North Slope Oil Fields

The facilities at Prudhoe Bay have undergone numerous changes as the owners continually modify operations to ensure continued production. The field originally thought to have a life of

20 years has just passed 23 years of operation. Consider these statistics (BP Alaska – Prudhoe Bay Visitor Pamphlet). In 1978, the average well produced 6,500 barrels/day of liquids; in 1998 the average well was producing 748 barrels/day. In looking at the make-up of that production in 1978, producing 1 barrel of oil required processing approximately 1 pint (.125 gallon) of water and 774 cubic feet of natural gas. That same barrel of oil in 1998 required the processing of 68 gallons of water and 10,050 cubic feet of natural gas. The amount of flowlines in the western half of the Prudhoe Bay field (known as the Western Operating Area or WOA) has increased from 140 miles to 345 miles of oil flowlines and added 86 miles of water flowlines. In 1978 there was little or no cost associated with corrosion control and repair. The 1998 budget for the WOA for that category was $36 million.

The end result is continued modification to the facility as well as increased maintenance and repair in what is now a nearly 30-year-old facility. While the Prudhoe Bay operation is classified as a mature field, its very existence depends upon change; without a process to manage this change, the very integrity of the facility is at stake.

Technical Integrity can be viewed as the process or system that ensures that a facility operates within the bounds of its design parameters throughout the life cycle of that facility. Technical Integrity can be achieved through communication - the communication of the definition of a facility in all areas and the communication of change in any of those characteristics. Central to Technical Integrity are understanding and managing change. Change can come from many sources, including operating parameters (temperature, pressure, velocity, product components), physical structures (wall thickness of pipe, addition of equipment), standards and procedures (regulations, operating procedures, maintenance procedures) and personnel (organizational changes). Any changes in these areas can affect the integrity of a facility.

As can be seen by the discussion above, change is inherent in the North Slope operations and an approach is needed to manage these changes and their associated risks. The initial impetus for this approach was provided by the Process Safety Management (PSM) standard (OSHA Standard 29 CFR 1910.119) which became effective on May 26 1992. This standard advocates a comprehensive hazard analysis program to evaluate those chemical processes that contain more than 10,000 pounds of flammable liquid, in order to prevent process-related incidents that could release hazardous chemicals. The process industries were given 5 years to completely implement this program, with the first milestone of no less than 25 percent of the initial process hazards analysis to be completed by May 26, 1994. According to Darrin W. Fleming and Velumani Pillai [8], "The PSM standard advocates a comprehensive hazard analysis program to evaluate the process . . . and recommends that several lines of defense be incorporated in the design and operation of the process." The authors specifically mentioned three required lines of defense:

- Well-documented change control policies and procedures - both administrative and operational.
- Advanced consideration, notifications and approvals of procedures in the areas of safety and the environment before any change is made to materials, equipment, technology, or utilities.
- A preventive maintenance program related to equipment performance.

In 1994 BP Exploration (a world class oil and petrochemical company; http:// www.bp.com) instituted two programs at their Alaskan facilities. The first was a required program to comply with the federally mandated OSHA PSM standard. The second was an internal BP program known at that time as OIAS (Operational Integrity Assurance System), which was a corporate response to the OSHA regulation. This program has since been renamed Getting HSE (Health, Safety, Environment) Right (gHSEr). These programs were put in place with the specific objective of managing risk at the facilities and assuring that the integrity of the plants is maintained. Six years after their initial implementation, these programs are still in effect. Compliance audits, at the Alaskan facilities as well as other BP operating facilities, to evaluate the level of compliance to both the PSM regulations and the BP gHSEr expectations, have taken place during this past time period.

While there is general corporate awareness of these programs and their importance, more specific understanding of the system requirements for the program and how best to implement them are less well understood. The underlying root cause of this is felt to be a lack of what could be loosely defined as an appropriate management system. The implementation of management systems is often initiated through a process that consists of listing requirements and developing a series of standards or procedures – all organized into matrices and checklists. This approach can be thought of as a vertical process, because the user, in wanting to know what procedure to follow, will look up his department or function on a matrix and then scan *down* until he finds the appropriate procedure. While effective in organizing information, this approach is limited, as it does not consider the influence that different departments, groups or organizational components have on each other. It tends to isolate different teams from each other, and does not consider that these procedures need to be integrated *across* the organization to be fully effective. This lack of horizontal integration impairs the full efficiency of the management system that is being implemented and could lead to a complete failure of the system.

These programs (PSM, gHSEr) are soft in nature; that is, they define expectations rather than specific step-by-step rules. The understanding of these expectations and how to apply them are constrained by mental models (what does it look like, how does it work). The absence of this "mental model" impedes or frustrates the understanding by those involved in the implementation and operation of the program. One motivation for this study comes from the desire to improve the performance of the MoC process through the implementation of a management system; and to identify tools to help visualize the mental model of the system, thus enhancing the performance and understanding of the system.

2.0 Management Systems

Management can be defined as the process of planning, organizing, leading and giving control or direction to an organization, its operations and projects, working with and through others. A *system* is a collection of elements that work together; therefore we can define a management system as a collection of elements or activities working together to give direction and feedback to an organization. In other words, a management system is an approach whereby a series of components or steps are put together to solve a problem or make an improvement in internal efficiency and external effectiveness.

Much of the work today in management systems are related to or based upon the work of Edwards Deming [38] in the field of Quality Management. Like control systems, management systems define inputs and outputs and determine how best to measure the difference between the two and feed that difference back to the controller. In Deming's case this resulted in the Plan-Do-Check-Act cycle where "you plan your work, you do your work, you check on what has taken place, and then you act on what you have found out to correct any deviations." One of the key attributes of a management system is this action of continuous improvement through the repetition of the P-D-C-A cycle.

The major examples of these "technology" management systems are the various Quality Management Systems (ISO 9000), Environmental Management Systems (ISO 14001) or Safety Performance Systems (future ISO 12000). The PSM standard is not a management system, but rather a set of expectations that a management system is required to implement. While these systems may be legislated, companies have begun to develop their own response to these challenges; these include companies such as BP Amoco (gHSEr - Getting HSE Right). These companies are motivated not only by federal regulation, but also by the desire to improve operational performance. They also want to assure their shareholders that their operation is safe and will do no harm to the environment, and that the product being manufactured is of the highest quality. Successful implementation of these systems is necessary to protect their corporate reputations - a commodity essential for their continued exploration and license to operate.

The oil industry (especially in Alaska) has migrated to a position that defines a management system or a technology management system through 5 key sections or components. These are very consistent with Deming's P-D-C-A approach, but the "Do" has been expanded into two components. For purposes of this report we will use the following five components and descriptions as used at BP Amoco.

Scope – The scope defines the boundary of application of a specific management system. Without this definition the process that is developed may be too broad or too narrow for the scope. This is the most important aspect of a management system, for it allows the appropriate resources to be assigned to the work at hand. An example of "scope" relevant for the subject of this study would be an MoC system for changes occurring in the operations function of the Prudhoe Bay facility. The process defined for this scope would include changes related to operating conditions and procedures, but would not include changes in engineering, maintenance or inspection.

Process – The process is a series of activities that transform an input into an output or bring about a result. The process defines the actual steps that must be taken to implement the management system by defining the work requirements in specific written documents called procedures.

Organization – The organization identifies the specific personnel that have roles and responsibilities for implementing the process as defined in the written procedure. Clear definition of the organization, as it has been structured to implement the process for appropriate scope, assures that appropriate resources are available to implement the management system.

Performance Measures – To satisfy that the defined goal of the scope of the management system is being attained, specific performance measures are defined for the process. Again using the MoC system as an example, one step in the process is the review of the change by a technical specialist. A performance measure could be the number of days a change is in review at this stage, or the number of change requests reviewed by the same technical specialist. Both performance measures give an indication of how the system is performing, which allows gaps to be determined (between planned and actual targets) and corrective actions to be taken.

Feedback – In order to take corrective actions and achieve the goal of continuous improvement, feedback to those responsible for the performance of the system must take place. Feedback allows lessons learned to be developed and applied to the other aspects of the system - scope, process, organization and the performance measures. In the overall development of the system, the opportunity for feedback must be identified and defined. Continuing with our MoC example, a performance measure for the number of changes reviewed by a single technical specialist could be defined. The planned feedback for this performance measure might be: When the number of changes in review exceeds 25, a report will be generated and sent to the appropriate manager. The manager, with this information, can take corrective actions such as obtaining additional resources. Another example of feedback in a management system would be the prescribed review of the past year's performance of the MoC process. This feedback would look at the lessons learned and the actual performance, and use this information to set new goals for the overall system. This could include the modification of the scope, changes in the process (including organizational resources) and the setting of new performance measurement targets.

Figure 2 graphically represents this five-component management system. The important issue is that this is a continuous effort and that feedback leads to a revised scope – with the intent of continuous improvement.

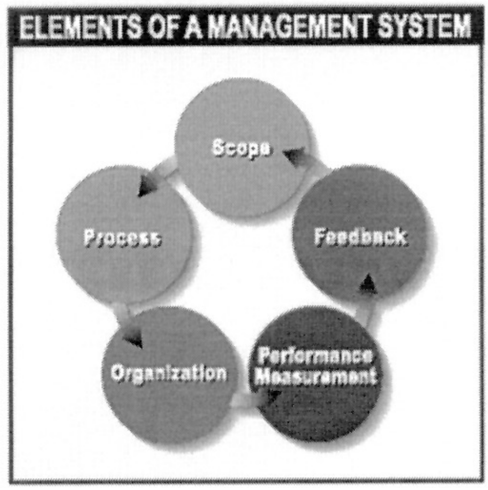


Figure 2 – Representation of a Management System

3.0 Change and Management of Change (MoC)

Random House Collegiate Dictionary defines *change* as (1) to make different the form, nature, content, future course, etc. of something; (2) to transform or convert. OSHA 1910.119 defines change to "include all modifications to equipment, procedures, raw materials, and processing conditions". These definitions are consistent with the application at oil production facilities, where modifications to equipment, operating procedures, etc., are making different the form, nature and future course of the facilities. Change is occurring constantly as discussed in Section 1.0; not only in changes in equipment and operating procedures as the field ages, but as new fields are developed and their production sent to the existing facilities. Without those changes there would be no oil production on the North Slope; and as a result of that, management of those changes is essential not only to the well-being of the facility, but to the economic well-being of the State of Alaska.

The expressions - change management and management of change - are used and defined in many different ways in the literature. For the purposes of this report we are dealing at the micro-level of change: not changes in the corporate strategy or in the development of human resources, but in the nuts and bolts of modifying piping and machinery. Change management is fundamentally about how people deal with change, their attitude towards it and how it is integrated into the culture. Without change, there cannot be improvement; without change, there can be no growth. Change is inevitable and necessary. It is not something to be avoided or prevented, but something to be encouraged and managed regardless of whether it occurs at the macro level or the micro level of this paper. The integrity of the facility and its ability to fulfill its operational requirements will be limited by its ability to manage change. The importance of seeing management of change as a system and as a vehicle for continuous improvement helps define the reasons for using a system based simulation as a tool for improving the performance of the North Slope MoC process.

For purposes of this report, define MoC as the system put in place to manage any change impacting the facility (organization, process, material, equipment, procedures, etc.) through risk analysis and communication of the impact and scope of that change to all affected parties in the organization. As this is a system, the MoC program should identify the *scope* or affected area; the *process* that will be used for the scope; the *organization* that will perform the review and implement the change; the *performance measures* that will be put in place to assist in the management of the system; and the kinds of *feedback* and how that feedback will be used to facilitate continuous improvement and add to the corporate memory.

4.0 System Dynamics

A *system* is defined as a collection of elements that interact over time to form a unified whole and operate towards a common purpose. The term *dynamic* refers to change over time. A dynamic system is therefore a system in which the components interact to simulate change over time, and system dynamics is an approach used to understand how those systems change over time. A system dynamics model is the representation of the structure of that system.
System dynamics is an outgrowth of traditional control theory. Control theory (or more accurately, feedback control theory) was developed to explain and design mechanical operating control systems (such as speed control on turbines).

This approach has since been developed to model nature, neural networks and organizations. A feedback control system has a controlled variable (output), a reference variable (input), a measurement device (allows for the generation of an error signal) and a controller (some way to send a correcting signal back to the input). The simplest example of a feedback control system is the thermostat in a house as depicted in Figure 3.

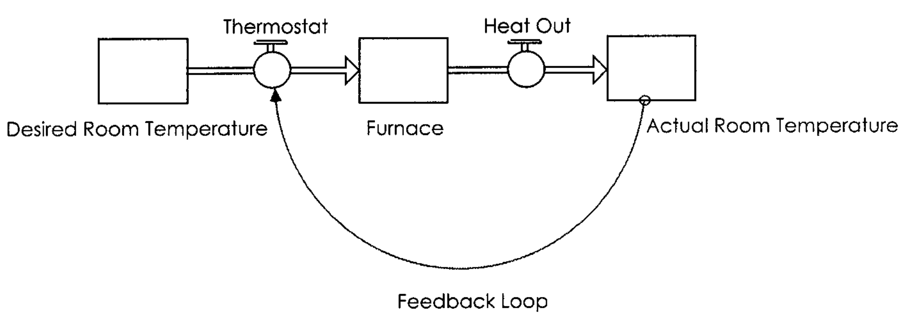


Figure 3 – Simple Feedback Loop

The input (desired temperature) is set at the thermostat. The thermostat sends a signal to the furnace for heat, the house heats (with external temperature generating a disturbance to the house temperature) and the actual room temperature is measured (output). Feedback is sent back to the thermostat allowing the thermostat to turn off (temperature reaches the input setting) or to turn on (temperature is below the input setting). This basic feedback loop is what gives rise to the entire field of system dynamics. This process has been used to model large population groups, natural resources and other significant systems.

An extension of system dynamics is system thinking. It is a much more general approach to the field, rooted in the philosophy of cause and effect, versus the control loop feedback theory of system dynamics. System thinking is a way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behavior of a system.

System thinking has been described as system dynamics without the math. A systems approach to a problem looks at the entity as a whole as opposed to looking at the entity as a collection of independent components or parts. The most well-known system is our ecosystem, where the planet and its inhabitants are treated as a whole. This could be considered a suprasystem; that is, an overarching system, consisting of a number of subsystems. A change in one of the subsystems (water for example) affects all other parts of the suprasystem. Keeping this philosophy in mind an analyst could then develop a series of subsystems, test them independently and then tie them together to create a suprasystem.

One objective of this project, as discussed in Section 1.0, was to apply system dynamic modeling techniques to the Prudhoe Bay MoC process. A model will be developed in using six subsystems that are based on the actual six-stage process currently in place on the North Slope and described in Section 5.0. These six subsystems are then linked together to create a suprasystem that simulates the overall MoC system.

5.0 Analysis of Existing Process

Prior to the development of a simulation model of the Management of Change (MoC) process or recommending a web-based system to enhance the performance of that process, we have to understand what is currently taking place. The basis for the analysis will be the review of the current MoC procedure and a review of the historical MoC database. The review will focus on the six-stage MoC form and the dates and times for each of the six stages. The objective of this analysis will be to gain a broad understanding of the actual operation of the process; and with sufficient statistical information, to be able to draw conclusions as to the efficiency of operation and identify any bottlenecks in the system. While the results of this study will apply to all operating fields on the North Slope, this review was conducted at the Prudhoe Bay facility. This facility had the most comprehensive set of records to review and the types of changes and the problems encountered are similar to the other fields.

The MoC process at Prudhoe Bay is driven primarily by a six stage "MoC Form" which was created to fulfill the requirements of the Alaskan HSE Standard on Management of Change, the BP gHSEr program, and the OSHA 1910.119 PSM standard. There are six stages to the MoC process, each with a specific approval mechanism. These stages are described below and it is important to note that the level of review, design and energy spent is to be "fit for purpose"; that is, appropriate to the cost and level of risk of the change.

Stage 1 – Initiation: Prior to any action being initiated on a change, the first review is whether or not the activity being requested is in fact, a change. The PSM standard does not require any special action on those activities that are deemed Replacement in Kind. This stage then is required to make that determination. A technical authority reviews the request, verifies whether there is a true change and then approves the change for the next stage. The form itself has a series of guidance questions to assist in the review. The essential portion of the review is to acknowledge that while a replacement of, for example, a valve may appear to be a replacement in kind as the replacement valve may provide the same service, it may be a change if the operating procedures or maintenance procedures are changed. A simple example of this is a shower. If the water regulator previously used turned clockwise to obtain hot water and was replaced with a regulator that turned counter-clockwise, then a change has occurred. Remembering that communication is a key aspect to change management, the user, uninformed of this change, could be injured (or at least embarrassed). It is also important to note that at this stage preliminary economics have been developed to determine if there is a reason to make a change.

Stage 2 - Development Authorization: The second stage of the process is the approval to begin any engineering required to develop the requested change. At this stage the kind of Process Hazards Analysis (PHA) is determined. One of the information requirements of PSM requires that a PHA, of which there are a number of different accepted techniques, be done on all processes. If the change being initiated is a process change, a PHA must be done. In this development stage, it is expected that good engineering practices be followed and normal reviews take place.

Stage 3 - Technical and HSE Review: This step may be the most important step of the MoC process in terms of risk management. The Technical and HSE review is done as a peer review. It is not "reengineering" what was already done, but is specifically set up to review the design in terms of code compliance, health, safety and environmental concerns, and constructability. The intent is also to assure that those affected by this change are reflected in the review. Designated company technical authorities are used to perform this review, with the admonition to apply critical thinking to the review not negative thinking, but critical thinking – looking for potential problems with the objective of identifying these areas so a solution can be devised. One of the first places looked at is whether the PHA was completed in stage 2. The analysis should have identified problem areas and in the Technical and HSE review, this report is reviewed to confirm that any action items have been resolved.

Stage 4 - Authorization for Change: The authorization for change step is a milestone step. It is a stopping point for the end user to review the work done to date in terms of design and Technical and HSE reviews, and agree or disagree with that work. At this point the change form will have attached the results from the PHA and the Technical and HSE review, which will detail issues that have to be resolved or implemented prior to start-up. Additionally, if the change is one that is classified as a temporary change, then a date that the change expires is also established at this stage. If the change has major external implications or sets HSE precedence, the approval for implementing this change is sent to the President of BP Alaska, an operating company of BP Amoco. This is a very rare event and has not yet occurred in the Prudhoe Bay operation. With the authorization at stage 4, permission is given to "strike an arc" and actual implementation work can begin.

Stage 5 - End User Acceptance: The end user is responsible for ensuring that all documentation is complete, that operators have been trained, that operator procedures have been updated, and that a pre-startup safety review has been completed. This is the last time before the actual startup of the facility to look for potential problems and address them. The last activity to be completed prior to startup is to identify any outstanding punch list items - those items that can be completed after startup - and ensure that dates are scheduled for their completion. This would include drawings or engineering information as well as physical construction work.

Stage 6 – Records: Although the final step prior to closing out an MoC is the completion and updating of all documentation, it can be argued that this task is the most important. It is essential that documentation be done as quickly as possible to prevent the possibility of another change being based on erroneous information.

This MoC process as just described) is detailed in the MoC Flow Diagram (Figure 4).

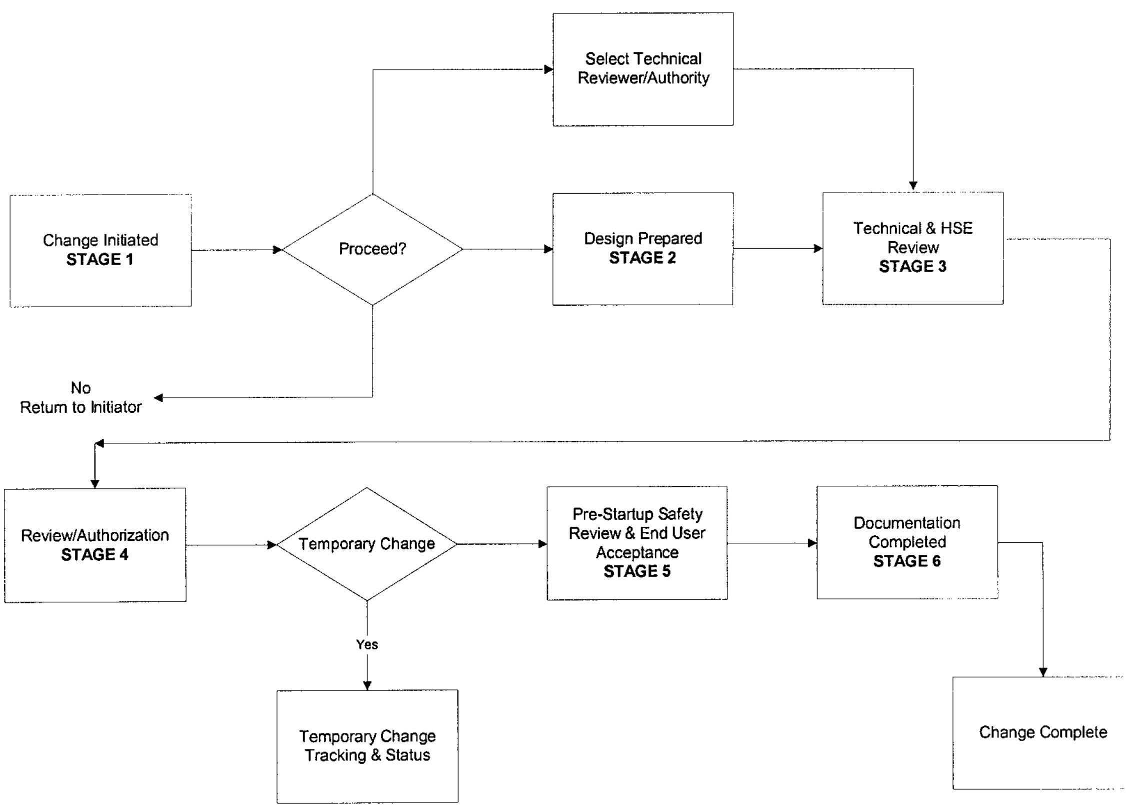


Figure 4 – MoC Flow Diagram

The analysis of the Prudhoe Bay MoC system was based on the review of four years of changes, from January 1996 through September 2000. The basis for this review was the MoC Change

Form. These changes cover all aspects of operations at Prudhoe Bay, including design changes, engineering changes, operational changes, maintenance changes and even organizational changes. 1364 changes were obtained and reviewed in two different manners. The first was a general review of the process based on the analysis of status-tracking spreadsheets. The information shown on these spreadsheets provided information on the number of changes initiated per year, the number of changes completed per year and backlog information, but could not provide information on the types of change (engineering, operation, etc.) or the length each stage takes to complete.

The second analysis was a more detailed review and was completed by taking a random sampling from this large population and then studying individual MoC change forms. This approach allowed us to analyze the duration of each stage and to determine the category or functional subject area of each change. This information will be used to both validate the systems dynamics model.

Of the changes that have been initiated since the beginning of 1996, there are records for 1364. Of this 1364, 48 changes had no record of start dates and were discarded, leaving a population of 1316 changes to analyze.

This macro review of the change order system at Prudhoe Bay, based on reviewing approximately 1316 change requests, provides the following performance information. On average (for the two typical years), the facility should expect to process 248 change requests per year. They should expect to reject approximately 14% of these requests during the Stage 2 Implementation phase, and of the remaining 214 changes have a completion rate of 84%. One other item to note in this discussion is the amount of backlog. At the time of this report there still was a backlog of 215 uncompleted changes, nearly a year's worth of change requests. This number had been reduced from 412 in 1999 to the 215 in the year 2000. As has been previously discussed, there was little work going on in 2000, allowing the backlog to be reduced. Attention must be given to this area to determine why the backlog is so high. It cannot be seen from the macro information, but interviews with those involved in using the existing process and a review of the sampling data indicate that the primary delay occurs in Stage 6 – Documentation. The Documentation stage is predominately involved with the completion of engineering drawings and updating of documentation. In most cases the change has been implemented and is in use. The follow-up documentation literally leaves the hands of the operating department and is transferred to the documentation group. When the author audited the process at the Prudhoe Bay facility, these files took up four file drawers of space and files were periodically being shipped offsite for completion. There is no urgency, no priority setting on which documents to update first, no resources, and no process for tracking the age of the documents; as a result the backlog builds.

In order to further refine our study, a sampling of the 1300+ requests was made with the intent of determining the major types of changes, the length of time spent at each stage and the number of temporary versus permanent changes. A 10% random sampling was done on the change records obtained. The records came from two distinct sources. The first and the majority of the records came from the project archives of completed work. The second set of records consisted of the "waiting final documentation" files on location at Prudhoe Bay. These files were of those activities that had been implemented, but the documentation was incomplete. The one source that was not used was the actual active records of changes currently in the Stage 1 through Stage 5 point of completion. These files numbered less than 100 and it was not considered to have a major influence on the over 1300 files obtained. Additionally, as these files were not yet substantially complete, they could not add to the historical database of information.

Figure 5 gives a comparison of the length of an average stay at each stage of the MoC. There is no Stage 1 duration as that stage is instantaneous: Stage 1 is completed (on the form) as soon as the change is initiated. The length of Stage 2 is the time from the completion of Stage 1 (initiation of the change and the beginning of Stage 2) and the completion of Stage 2. The average time for stage 6 to be completed is 258 days, with a maximum length of 834 days to complete stage 6. Of the samples reviewed that were complete, a "change" had an average age of 462 days. The first bar is the total length of changes, the second bar is the length through the approval stage (stage 4) and the remainder of the information is the length at each stage. The review from the sampled information clearly indicates that the majority of the time spent completing a change is in the documentation phase. Additional information, worth highlighting from that analysis is that of all the changes, 7% are classified temporary that is, having a finite life for the time the change is in effect.

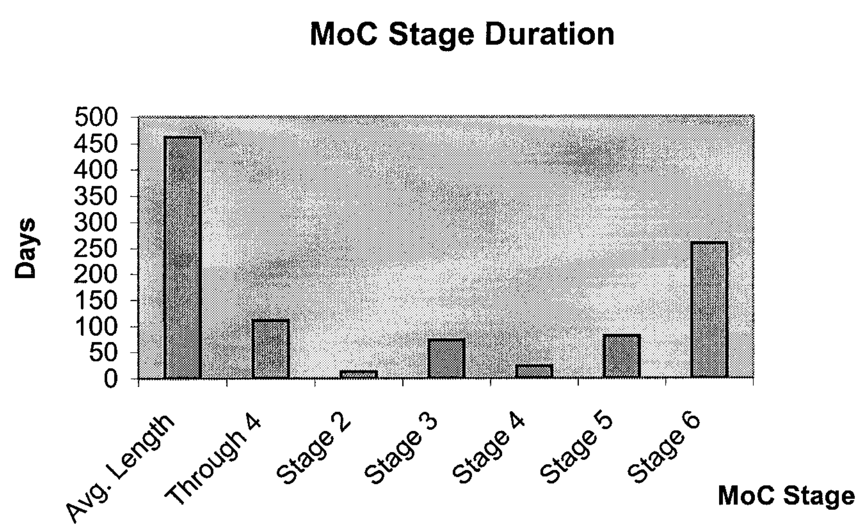


Figure 5 – Comparison of Length of Stages

6.0 Systems Analysis Simulation Model

A system dynamic model of the Prudhoe Bay Management of Change (MoC) process was created on the *ithink* programming. This model shows the relations between the stages and creates a representation of the effort, availability and time it takes to perform each of the different stages. The model is built in six sectors to model the six stages of the MoC process. The flow is the movement of the MoC form through the system; the stocks are the accumulations of the various reviews at the different stages. The advantage of this model is that it treats the system in an operational manner, which is useful for identifying the actual "levers" that can be pulled to change the performance. In this model, the availability of the technical reviewers and the length of review are areas that can be modified to change the system performance. The shift of mind set from a linear once-through model to a system point of view is critical if improvement is going to be made to the MoC process. Three fundamental changes in thinking must take place to move to a paradigm of systems thinking. "The first entails a shift from straight-line to closed-loop causality, a shift which engenders substituting a dynamic for a static orientation. The second shift is from an externally-oriented to an internally-oriented locus of responsibility for performance, the third is a shift from co-relational to an operational view of how things work." [26]

A systems dynamic model was created to simulate the actual performance of the MoC process in place at the Prudhoe Bay operating facility. The computer model using the software *ithink* is based on the actual movement of information and was developed with six subsystems to simulate each Stage of the MoC process. Two opportunities are possible through the use of a computer model. The first is the compression of time, allowing the model to simulate a process that takes hundreds of days in a matter of seconds. This allows for many iterations of the simulation, providing the opportunity to look for variances and uncertainties in the process. The second opportunity is the ability to ask "what-if" questions about the existing MoC process and actually experiment with modifications to the process prior to making any change in the management system.

The *ithink* program is an object-oriented language for the development of system models. The output from the model can be viewed at three different levels; the top level is the interface level where the model can be run through control panels developed by the analyst. These interface screens are included in Attachment 1. The next level is where the modeling components comprises combined to develop the system model. Finally, the third level are the equations themselves, which are automatically created from the model. Figure 6 shows the complete six-stage MoC model

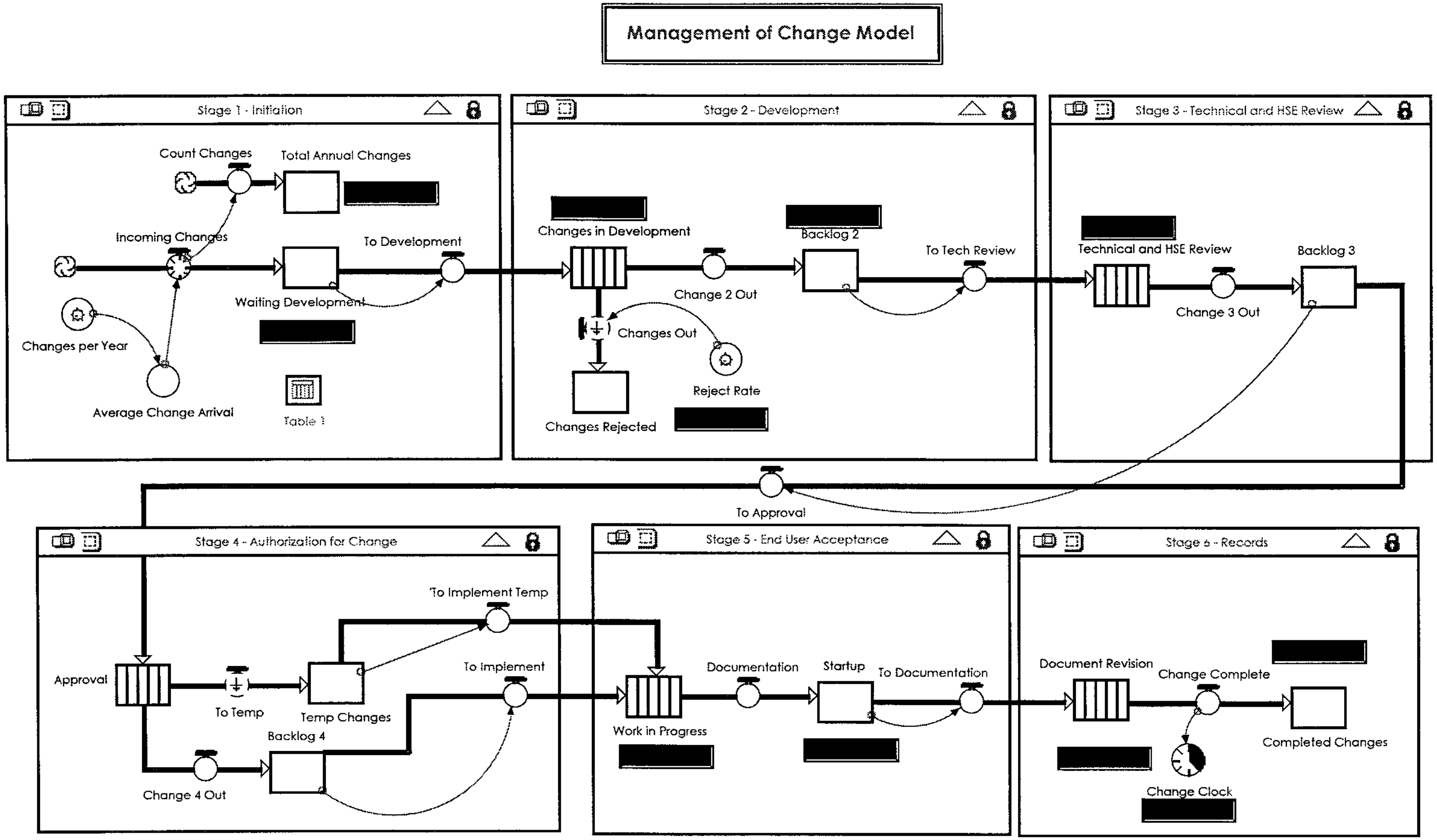


Figure 6 – Systems Dynamics Model of the MoC Process using *ithink*

There are four basic components or building blocks in the *ithink* language: they are stocks, flows, converters and connectors. Stocks are represented by a rectangle and can be considered to be accumulations; they collect whatever flows in and out of them. Because they accumulate, stocks act as buffers in the system; they fill or drain depending on the inflow and outflow. The model provides a number of different kinds of stock. In our model, it is the MoC "form" that is moving in and out of the stocks. Backlogs are those changes that have accumulated at any given stage. The second component is the flow represented by the pipe and regulator icon. The purpose of this component is to fill and drain accumulations in the stock. The "valve" regulates the flow and the flow rate is determined by algebraic expressions entered for the regulator. This flow can also be determined by feedback from different components in the system. The third component is the converter, represented by a circle. The converter serves as an "other" role in the software. In general it converts inputs into outputs, hence the name "converter". It holds values for constants, defines external inputs to the model, and calculates algebraic relationships. The final language component is the connector represented by an arrow line, sometimes called a wire. Connectors link stocks to converters, stocks to flow regulators, regulators to regulators, converters to regulators and converters to other converters. Their role is to allow for the transfer of information. In our thermostat example, a connector connects or carries the information of the actual room temperature back to the thermostat. It can be considered a feedback or a feed forward link.

The following gives a brief description of the development of the simulation model for each stage of the MoC process as shown in Figure 6. A typical simulation output from each stage is shown in the interface screens in Attachment 1. The basis for the values used for "processing time" is the average time for each stage as described in Section 5.0.

Stage 1 – Initiation

Prior to any action taken toward implementing a change, the first review is to determine whether it is a change. In the simulation, changes are generated at an average rate of 248 changes/year - the historical average at Prudhoe Bay Oil Field, as an exponentially distributed set of random numbers. The decision was made to use an exponential distribution rather than an even distribution to more realistically represent actual performance of how the changes are initiated. The changes "arrive" with a sense of randomness – 0 on one day, 4 on the next – which is much closer to what the reviewers in the facility were seeing as opposed to a steady state or in some specific pattern. A counter was added to this model just to verify that the number of changes over 365 days is consistent with the average of 248 determined from actual data. In the model this stock of changes is immediately flowed to the Development stage.

Stage 2 – Development

The development phase is that time when the change is fully engineered. All design work, process hazards analysis and procedures are written. Many things are happening in this subsystem. First the "Changes in Development" stock is being simulated by a conveyor stock. What a conveyor stock does is to simulate a transit time for the discrete flow entering it. That flow cannot leave the stock until it has completed its transit time. From analysis of actual data we know that the average length of time in this stage is 13 days. From historical data we know that approximately 14% of change requests are rejected; they either are not changes or after development a decision is made not to proceed with the change. This rejection rate is simulated by the flow out of the conveyor marked "Changes Out", and in terms of the model is considered leakage. To ensure that the time taken at the conveyor in each stage is not unduly modified, a buffer stock – identified as "Backlog 2" - has been added. In real life the work done at each stage is not dependent on the progress of work in the subsequent stage. This buffer zone allows the model to run unimpeded at each stage. Therefore, to see the true backlog at any given stage you must look at what changes are still in process and what changes are in backlog.

Stage 3 – Technical and HSE Review

The Technical and HSE Review is possibly the most important step in the process. At this stage all previous engineering is reviewed (not redesigned) with regard to constructability, HSE hazards during installation, review of operating procedures, etc.; all with the goal of determining on "paper" if there are any problems with the design or implementation plans. The logic used in developing the Stage 2 model was used here. A conveyor stock is used, with the transit time being equal to the average time changes are in the Technical and HSE Review stage – 73 days.

Stage 4 – Authorization for Change

The Authorization Stage is notable, because at this stage the Temporary Changes are identified and called out. This is important as these changes, while undergoing the same process, must be tracked separately as they are only supposed to be in effect a finite period of time. From the process perspective, this is the stage where the end user or client can review the work done on evaluating the change and assure that the facility is not creating a risk by implementing this change. Two simulation steps are used in this subsystem. Again, a conveyor stock was created with a transit time equal to average time of 23 days. Secondly, from historical information it is known that an average of 7% of the changes are temporary. Similar to Stage 2 then, a leakage is created (equal to 7%) out of the "Approval" conveyor to fill a stock marked "Temporary Changes". A buffer for the permanent changes identified as "Backlog 4" is created. Both stocks then flow into the next stage.

Stage 5 - End User Acceptance

Training, pre-startup safety review, manual updating, as well as the normal "mechanical" acceptances, characterize the End User Acceptance Stage. While all the documentation is not complete, it is felt that enough is complete to start up the process. The Work in Progress is modeled using a conveyor stock with a transit time equal to the average time of 81 days.

Stage 6 - Records and Documentation

The Documentation Stage is a critical step. Without proper and controlled documentation changes could be taking place on top of changes, leading to an uncontrolled process. This is one of the key areas of management and requires the closest attention. This is where the big backlog is, in terms of processing the changes, and this is the stage that has the longest duration. Also, at this stage in the model, a clock is included to identify the length of time it takes for each change to work its way through the system. The same logic for the conveyor stock has been applied but, as mentioned, the duration of the activity is long, an average of 259 days.

In general the model tracks the existing process very well. The rejection rate in Stage 2 and the temporary change percentage in Stage 4 match almost perfectly with the information discussed in Section 5.0. Additionally, the generation of changes in the Initiation stage works exceedingly well. The overall impression the model gives is one that represents the information obtained from Prudhoe Bay. Figure 7 compares the durations generated in the simulation against the data generated from the actual MoC Forms.

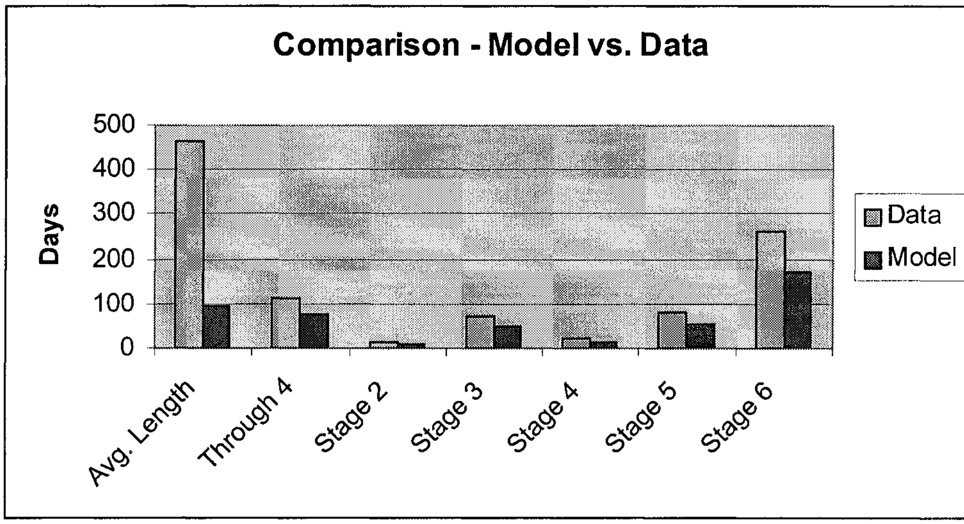


Figure 7 – Comparison of Model vs. Data

The simulation model appears to conform to the shape and magnitude of the actual information. There is a greater deviation in Stage 6, which could be related to the large deviation in average length. The average length of time that an MoC was in process was 462 days. Upon inspection the length of duration for the model was either a number in the high 400's or 0. The average reported total length of process was 441 days, very close to the 462, suggesting that this discrepancy is due to how the changes are generated in the model versus working from 100 forms.

This model still is a very coarse model relying on averages from a large body of data. It does not represent the actual work that takes place, but rather the length of time a document is in process. Further development of the MoC process at a manpower level would allow more finite adjustments in the model and would be a better management tool. Determining the actual number of engineers and technical authorities available at any given time and then working back from that to determine the time spent on each change could allow for that refinement. This information could be determined from taking an ongoing sample of the changes, perhaps using enhanced forms for additional data recovery. The model could also be expanded through the use of arrays to detail different kinds of changes (e.g. Design, Engineering, Operations and Maintenance) along with the different properties (in terms of duration at each stage), to give a more accurate depiction of the change process.

The intent of this simulation model is to assist in the actual managing of the MoC process. Ultimately this simulation model will allow a manager to perform "what if" analyses of changes in the system and how the system will react to different stimuli.

The value of a simulation lies in its ability to run multiple iterations of a model to provide information to a decision maker. From a systems perspective, the information is used to either take corrective action or determine the effects that a change in the system might have. The goal is to improve the performance of the system. In this study two different "what-if" analyses will be run. The first is to look at the overall backlog in the system under current conditions. The base case model was run for 365 days. What will happen at the end of 3 years? At the end of 5 years? Figure 8 shows the results of this analysis.

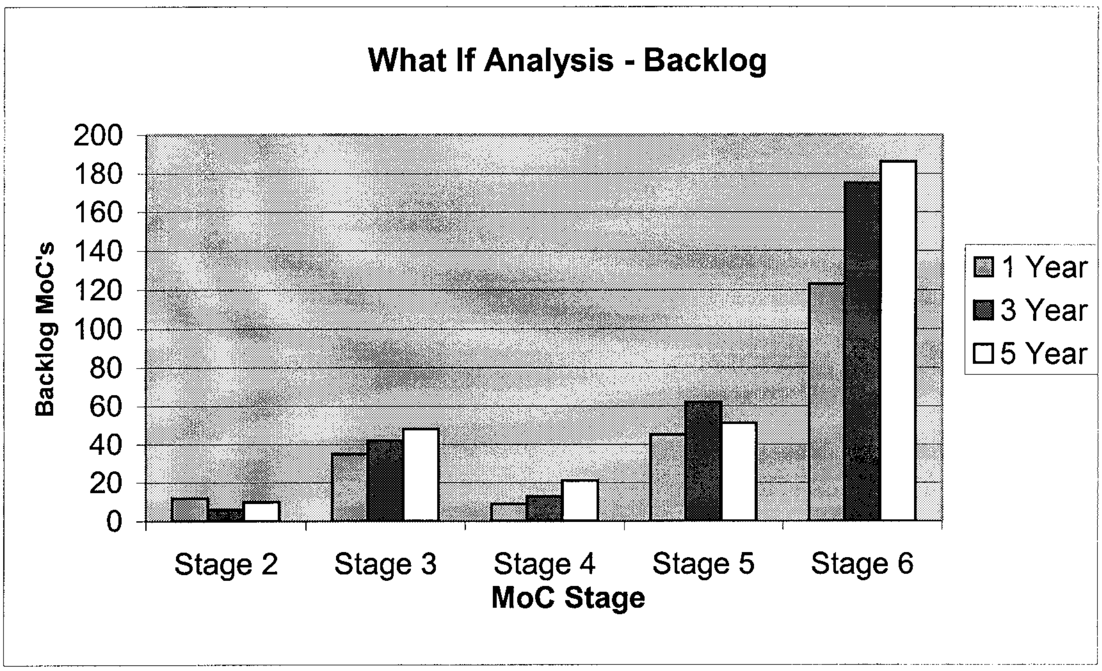


Figure 8 – Effect of Time on Backlog

These results show that in general, past one year, the amount of changes in backlog at any given stage, but particularly in Stage 6 – Documentation, plateaus. Therefore, at any given time it is reasonable to assume that there will be on average 160 changes in the documentation stage. This is good news for the manager: once a reasonable size of backlog is determined, then changes that are put in place to get to that level should be relatively stable over time.

In the second case, the number of changes per year is expected to increase from 248 to 400 due to increased activity in the field – new well tie-in's, change in process conditions and the modifications associated with those conditions. Figure 9 shows the plot of the backlog for both cases.

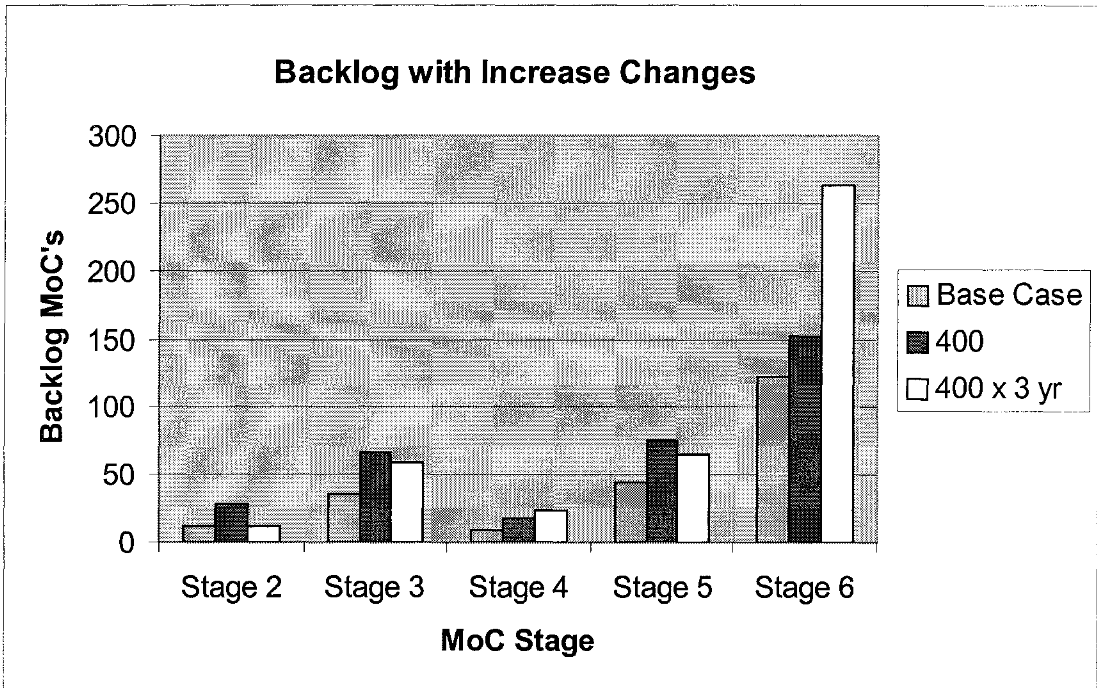


Figure 9 – Effect of Increased Changes on Backlog

As one would have expected, with an increase in changes per year, an increase in backlog should take place. In looking at the Base Case and the 400/year case, that increase is noticeable at every stage, but especially at Stage 3, the Technical and HSE review stage. This is a critical part of the MoC program and it may be advisable to increase the resources here. But what is not expected is the change in backlog in Documentation; there is a very small increase in the backlog versus the doubling that took place at the other stages. This can be explained in the lag time of Stage 6. The time to process a change in Stage 6 is 259 days, and over the course of 1 year there is not enough time to actually impact this stage. If you knew that the increased activity at the facility would be limited to one year, then there would probably not be a need to increase staff at this location. However, look at what happens if the increased activity extends to three years. In Figure 14, it was noted that the process was relatively stable and over time the backlog did not change much. But in this case, the backlog is over twice the base case, as the increased number of changes works there way through the system. Knowing this, a manager could monitor the activity that is causing the increase in changes to the system; and if that increase does appear to be abating, the manager could add additional staff in the Documentation stage – but only after the first year.

The goal of any modeling effort is to understand and explain the behavior of a complex system over time. From the information provided by the simulation, points of leverage can be determined (sensitivity analysis) and the unintended consequences of changes to the system, both good and bad, evaluated. But most importantly, the use of a simulation model such as this system dynamics model provides additional information through "what-if" analyses allowing the actual management of that system to take place.

7.0 Conclusions and Recommendations for Future Research

This model still is a very coarse model relying on averages from a large body of data. It does not represent the actual work that takes place. Further development of the MoC process at a manpower level would allow more finite adjustments in the model and would be a better management tool. Determining the actual number of engineers and technical authorities available at any given time (simulated through a probability of availability) and then working back from that to determine the time spent on each change could allow for that refinement. This information could be determined from taking an ongoing sample of the changes, perhaps using enhanced forms for additional data recovery. This model could also be expanded through the use of arrays to detail the different kinds of changes that take place (e.g. Design, Engineering, Operations and Maintenance) along with the different properties (in terms of duration at each stage) to give a more accurate depiction of the change process.

The intent of this simulation or model is to assist in the actual managing of the Management of Change process. Ultimately this simulation will allow a manager to "test fly" changes to the system (structure) and how the system will react to different stimuli (changes in manpower, availability, number of changes/year). How this can be used as a tool for managing the system of MoC needs to be further explored. An example of this would be as the backlog builds in certain areas, knowing how the system and the backlog might react to additional resources would be of value.

Another vision of the use of a simulation model in a more real time situation would be as part of an integrated web based MoC process. Figure 10 gives a broad representation of the architecture being proposed, a multi-level system that has, as its starting point, a roadmap of the system elements – Scope, Process, Organization, Performance Measures and Feedback. As information is obtained in a real time basis, the manager using the simulation model as a "flight simulator" could "experiment" with modification to the MoC process and see how those changes would impact the MoC system performance.

At its core, Management of Change (MoC) is about managing risk and, through that risk management, the preservation of the technical integrity of the North Slope operating facilities. The future of Alaskan Oil development depends on how the existing facilities respond to modification and change. It is hoped that through a simulation, as has been demonstrated here, positive enhancement of the process could be obtained. The use of a system dynamics model has the promise of creating a step change improvement in the understanding of how management systems perform, and specifically a step change improvement in the performance of an MoC system. Care must be taken in the design and implementation of such a system to ensure that the activities are being done is appropriate for the work and inherent risk. There is nothing so constant in the world as change -

> *"Observe always that everything is the result of change, and get used to thinking that there is nothing nature loves so well as to change existing forms and make new ones like them."*
> *Marcus Aurelius – Roman Emperor and Philosopher*

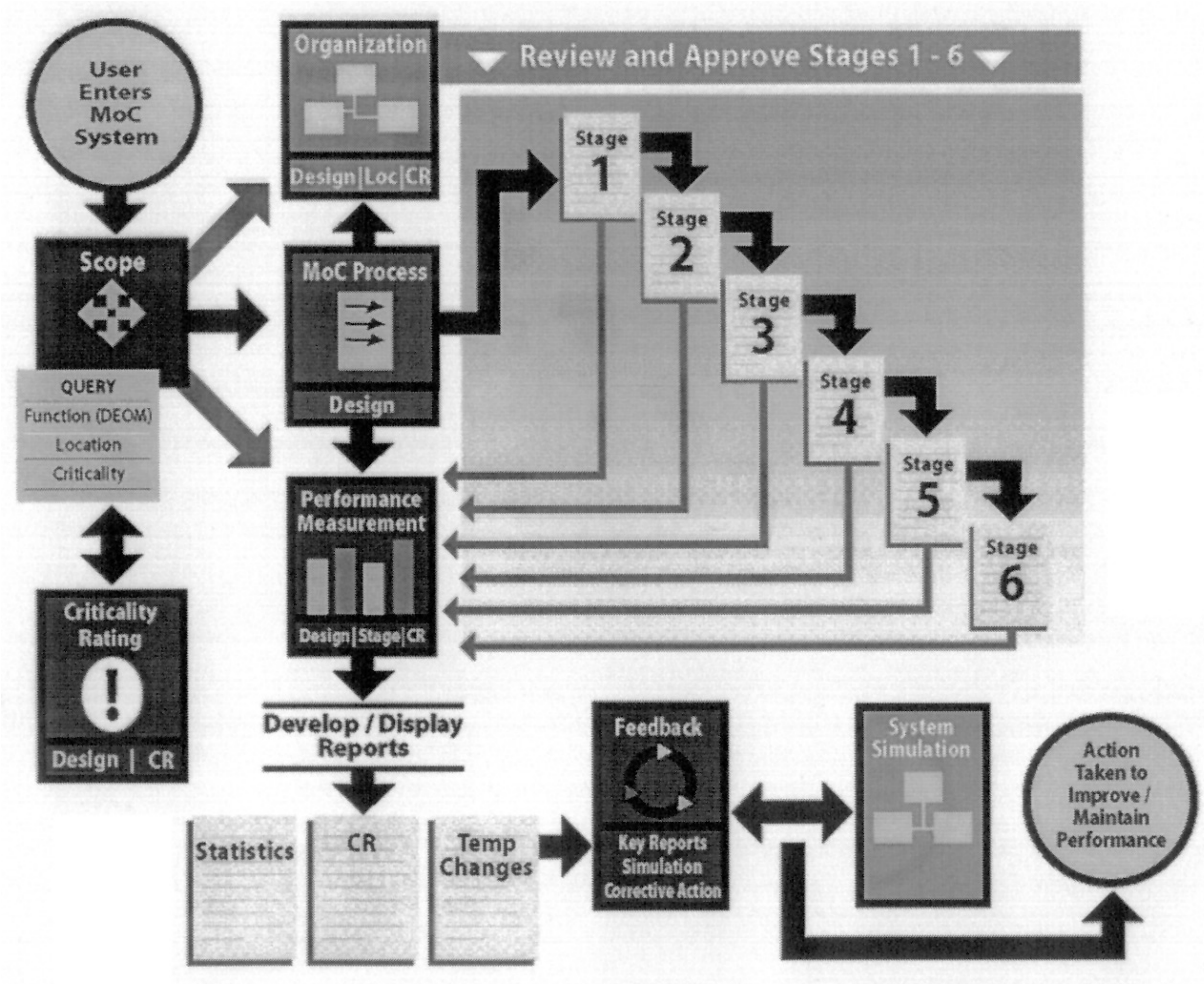


Figure 10 – Roadmap: Web-Based MoC System

8.0 References

[1] C. Alexander, Ishikawa, S., Silverstein, M., Jacobson, M., Fiksdahl-King, I., & Angel, S.W. *A Pattern Language.* New York: Oxford University Press, 1977.

[2] T. Asahi, D. Turo and B. Schneiderman, "Using Treemaps to Visualize the Analytic Hierarchy Process," *Information Systems Research,* pp.357-375, 1995.

[3] Jan O. Borchers, "A Pattern Approach to Interaction Design," *Proceedings of the DIS 2000 International Conference on Designing Interactive Systems,* August 2000.

[4] Jan O. Borchers, " Interaction Design Patterns: Twelve Theses," *CHI 2000 Patterns Workshop,* April 2000

[5] A.H. Church and J. Waclawski, " OD practitioners as facilitators of change: An analysis of survey results," *Group and Organization Management,* pp.22-66, March 1996.

[6] N.S. Dedhia, "Survive business challenges with the total quality management approach," *Total Quality Management*, pp. 265-272, July 1995.

[7] Thomas Erickson, "Lingua Francas for Design: Sacred Places and Pattern Languages," *Proceedings of the DIS 2000 International Conference on Designing Interactive Systems,* August 2000.

[8] D.W. Fleming and V. Pillai , *S88 Implementation Guide: Strategic Automation for the Process Industries.* New York, NY: McGraw Hill, 1999.

[9] G.G. Freda, J.V. Arn, and R.W. Gatlin-Watts, "Adapting to the speed of change," *Norcross,* pp.31-33, Nov./Dec. 1999.

[10] U.A. Ghani, "Holistic reengineering," *Management Review*, p. 62, January 1996.

[11] V. Grover, "From business reengineering to business process change management: A longitudinal study of trends and practices," *IEEE Trans. Eng. Management,* vol. 46, no. 1, pp.36-45, 1999.

[12] M.D. Hansen, "Taming the paper tiger," *Professional Safety,* pp.18-23, October 1998.

[13] M.D. Hansen, "Engineering design for safety: Petrochemical process plant design considerations," *Professional Safety*, pp. 20-25, January 2000.

[14] James R. Hemsath and Jang W. Ra, "Web-based, Real Time Protocol For Management Of Change In A North Slope Oil Exploration And Production Operation" *Proceedings of Portland International Conference on Management of Engineering and Technology,* July 2001.

[15] B.W. Hennestad, " Implementing participative management: Transition issues from the field," *Journal of Applied Behavioral Science,* pp. 314-335, September 2000.

[16] T. Hughes, T. Williams and P. Ryall, "It is not what you achieve it is the way you achieve it," *Total Quality Management,* pp. 329-340, May 2000.

[17] H.R, Kavianian, "Process safety management," *Professional Safety,* pp. 16-19, September 1998.

[18] Thomas K. Landauer, *The Trouble with Computers.* Cambridge, MA: The MIT Press, 1995.

[19] W.F.G. Mastenbroek, "Organizational innovation in historical perspective: Change as duality management," *Business Horizons,* pp. 5-14, Jul./Aug. 1996.

[20] R. McIvor and M. McHugh, "Partnership sourcing: An organization change management perspective," *Journal of Supply Change Management,* vol. 36, no. 3, pp.12-20, 2000.

[21] Kevin Mullet and Darrell Sano, *Designing Visual Interfaces.* Englewood Cliffs, NJ: Prentice Hall PTR, 1995

[22] Jakob Nielsen, *Designing Web Usability.* Indianapolis, IN: New Riders Publishing, 2000.

[23] North, C. and B. Schneiderman, "Snap-Together Visualization: A User Interface for Coordinating Visualizations via Relational Schemata," *University of Maryland Report,* College Park, MD, 2000.

[24] M.A. Reidelbach, "Engineering change management for long-lead-time production environments," *Production and Inventory Management Journal*, vol. 32, no. 2, pp. 84-88, 1991.

[25] Jang W. Ra, "Hierarchical Decision Process," *IEEE Trans. Eng. Management*, pp.595-599, July 1991.

[26] B. Richmond and S. Peterson, *An Introduction to Systems Thinking.* Hanover, NH: HPS, 2000.

[27] R.H. Rouda and M.E. Kusy, "Development of human resources: Organization development- the management of change," *Tappi Journal,* pp. 253-255, August 1995.

[28] T.L. Saaty, *Decision Making with Dependence and Feedback: The Analytic Network Process.* Pittsburgh, PA: RWS Publications, 1996.

[29] T. Savolainen, "Leadership strategies for gaining business excellence through total quality management: A Finnish case study," *Total Quality Management,* pp. 211-226, March 2000.

[30] D.M. Schneider and C. Goldwasser, "Be a model leader of change," *Management Review*, pp.41-45, March 1998.

[31] G.D. Sentell, "Creating the quality management system: Change and organizational culture," *Tappi Journal*, p. 275, April 1989

[32] Ben Shneiderman, *Designing the User Interface.* Reading, MA: Addison-Wesley, 1998.

[33] J.H. Statzer, "An integrated approach to business risk management," *Professional Safety,* pp. 30-32, August 1999.

[34] Ian Sutton, *Management of Change.* Houston, TX: Southwestern Books, 1998

[35] Gabriel Szulanski, " The Process of Knowledge Transfer: A Diachronic Analysis of Stickiness," Prepared for the Wharton School, University of Pennsylvania, June 14 1999.

[36] M.D. Topf, "Managing Change," *Occupational Hazards,* pp.43-44, July 2000.

[37] Edward R. Tufte, *Visual Explanations.* Cheshire, CN: Graphics Press, 1997.

[38] Mary Walton, *The Deming Management Method.* New York, NY: Dodd, Mead and Company, 1986.

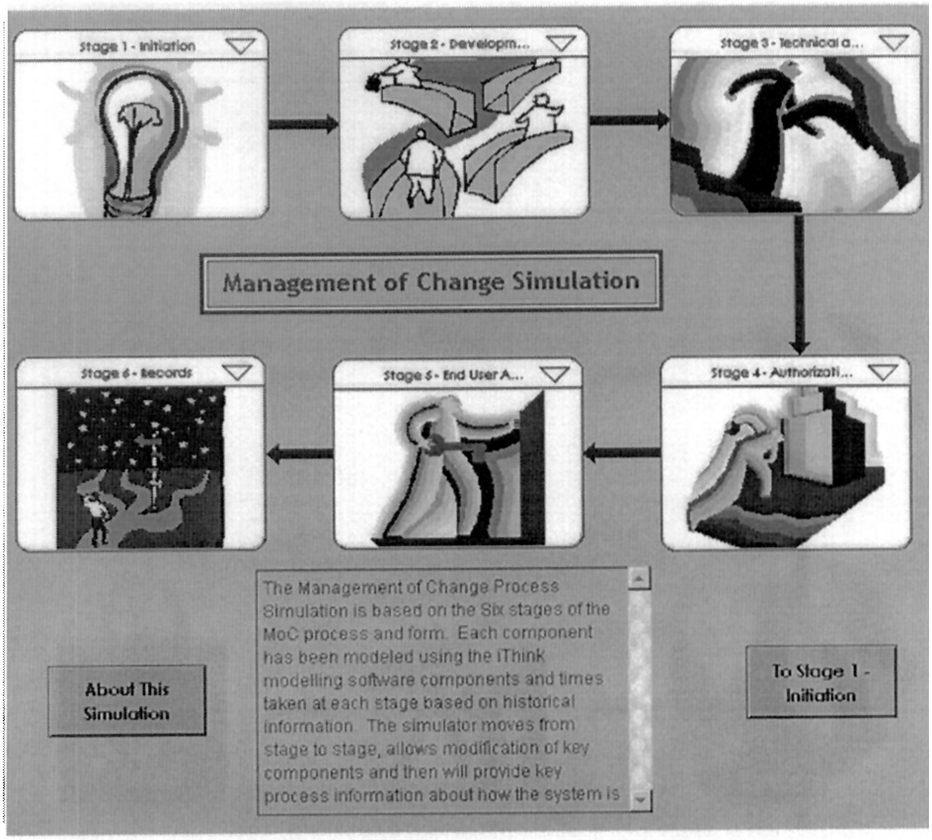
[39] Martijn van Welie, G.C. van der Veer andA. Eliens, "Patterns as Tools for User Interface Design," for the Department of Computer Science, Vrije University, Amsterdam, Holland, 2000.

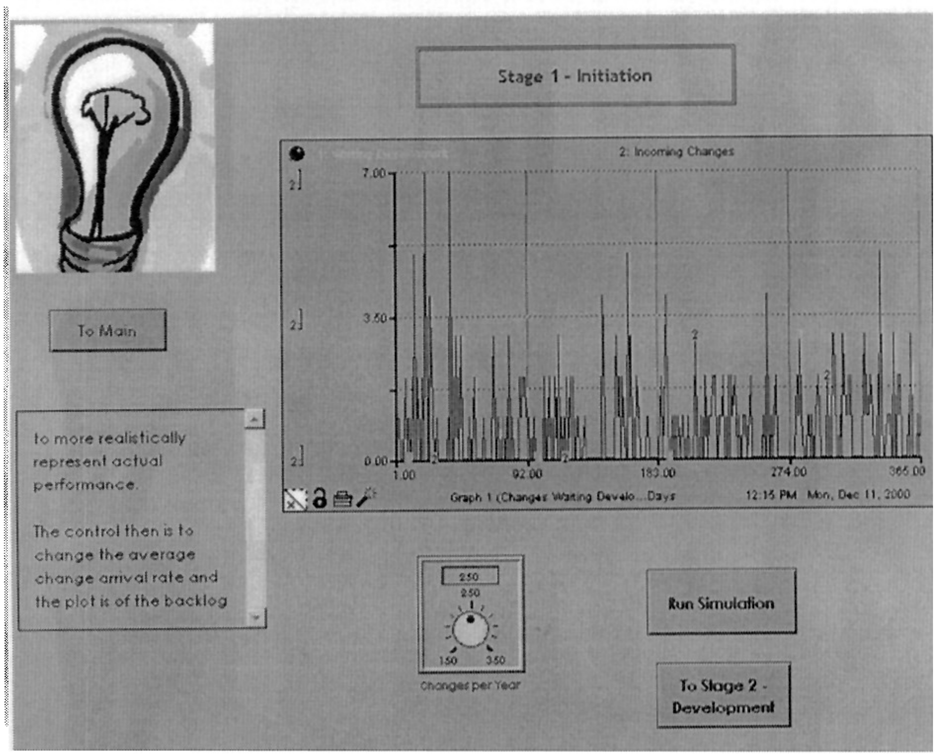
[40] Jarke J. van Wijk and Huub van de Wetering, "Cushion Treemaps: Visualization of Hierarchical Information," *IEEE Symposium on Information Visualization*, October 1999.

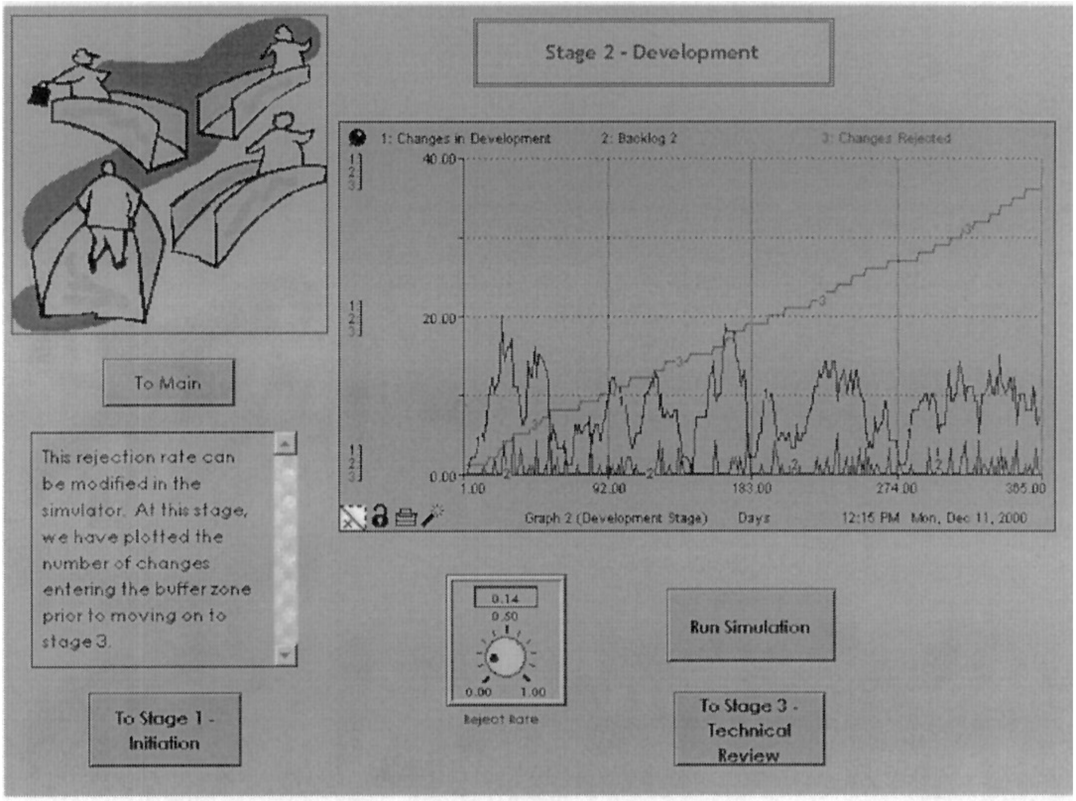
[41] Richard Saul Wurman, *Information Architects.* New York, NY: Graphis, 1997.

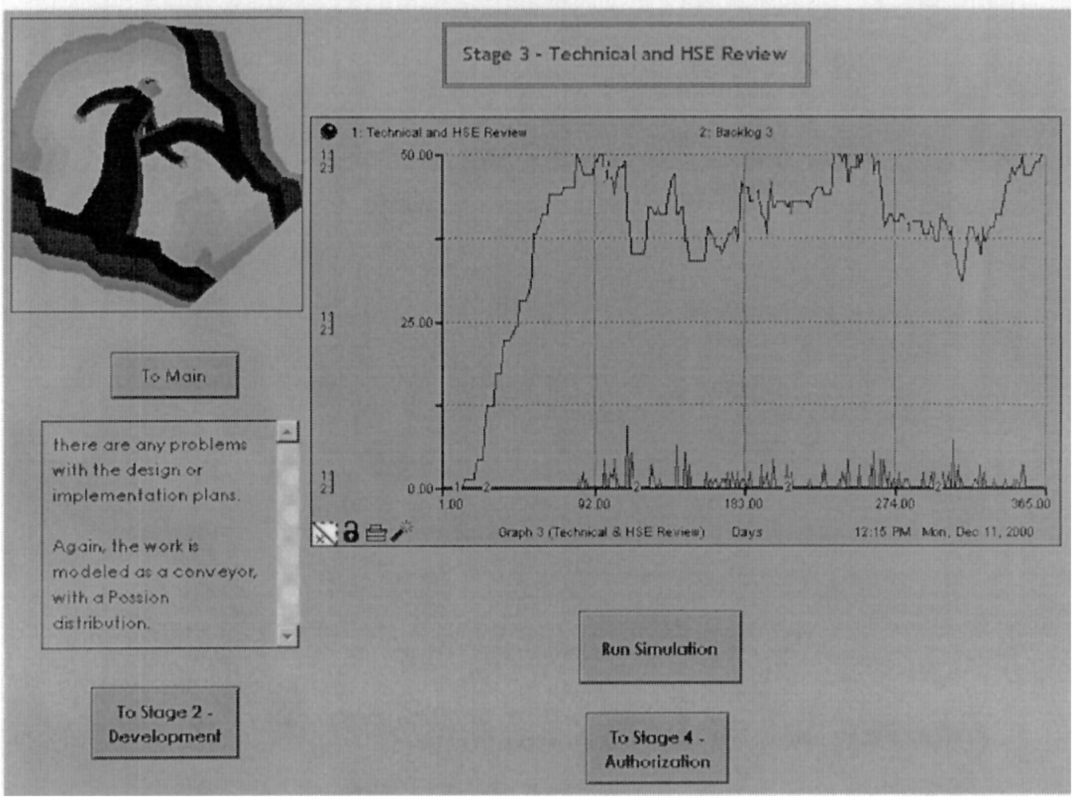
Attachment 1

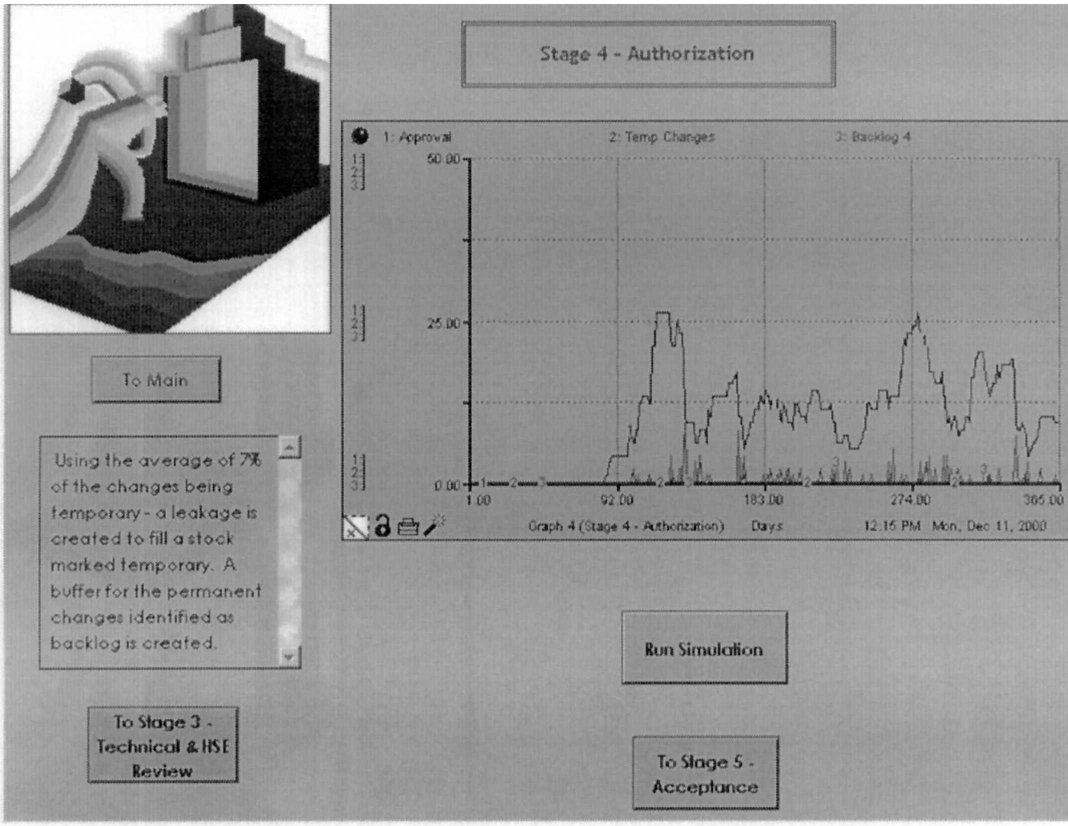
System Dynamics Model Interface Screens

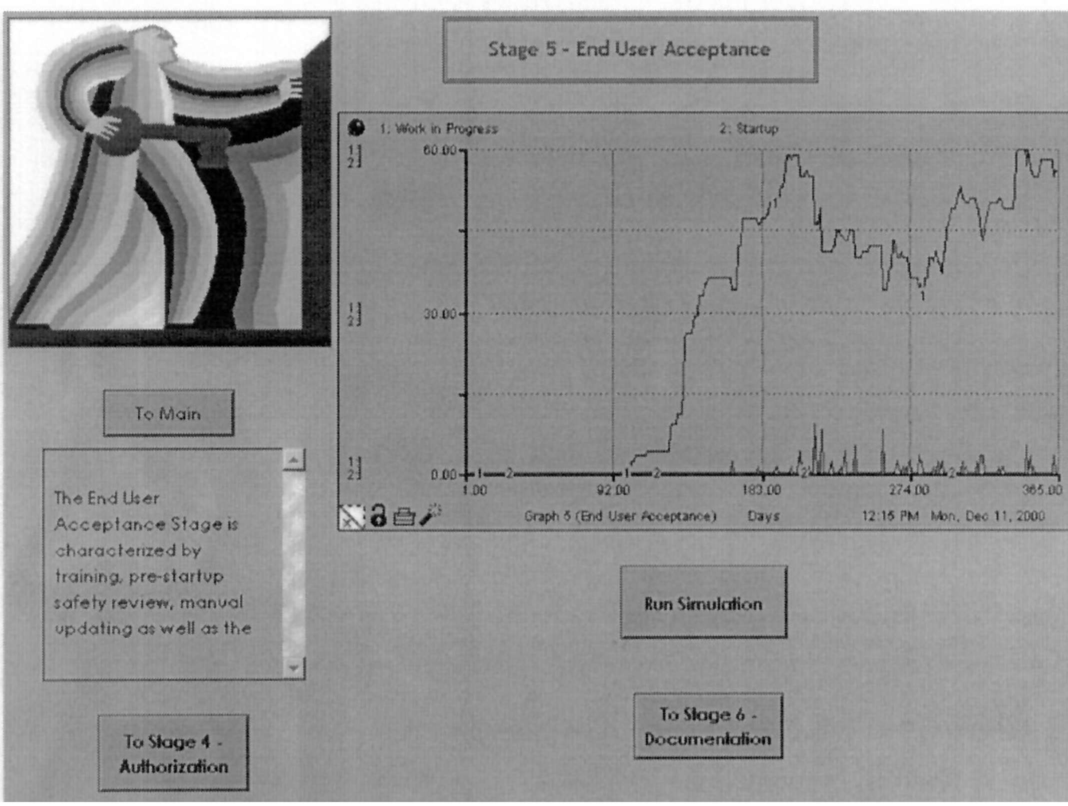

Stage 1 - Initiation
Stage 2 - Developm...
Stage 3 - Technical a...
Management of Change Simulation
Stage 6 - Records
Stage 5 - End User A...
Stage 4 - Authorizati...
About This Simulation
The Management of Change Process Simulation is based on the Six stages of the MoC process and form. Each component has been modeled using the iThink modelling software components and times taken at each stage based on historical information. The simulator moves from stage to stage, allows modification of key components and then will provide key process information about how the system is
To Stage 1 - Initiation

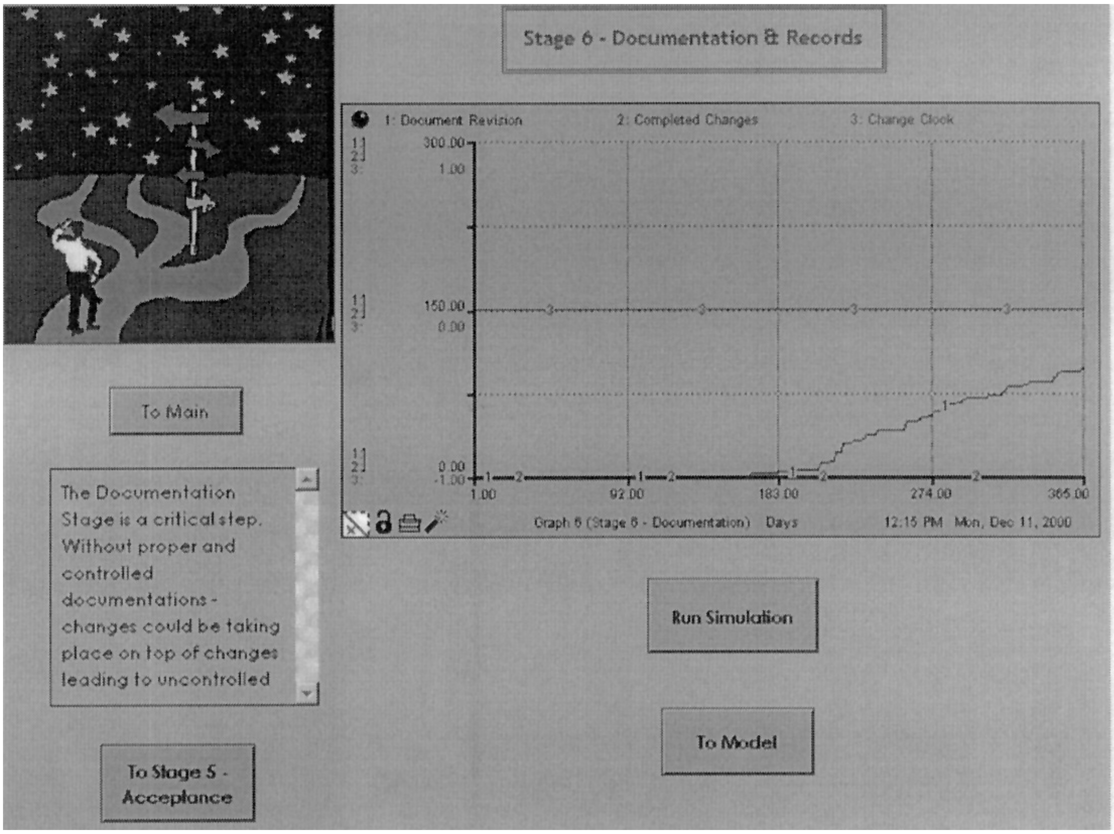

Stage 1 - Initiation
To Main
to more realistically represent actual performance.
The control then is to change the average change arrival rate and the plot is of the backlog
2: Incoming Changes
7.00
3.50
0.00
1.00
92.00
183.00
274.00
365.00
Graph 1 (Changes Waiting Develo... Days
12:16 PM Mon, Dec 11, 2000
250
150
350
Changes per Year
Run Simulation
To Stage 2 - Development


Stage 2 - Development
1: Changes in Development
2: Backlog 2
3: Changes Rejected
40.00
20.00
0.00
1.00
92.00
183.00
274.00
365.00
Graph 2 (Development Stage)
Days
12:15 PM Mon, Dec 11, 2000
To Main
This rejection rate can be modified in the simulator. At this stage, we have plotted the number of changes entering the buffer zone prior to moving on to stage 3.
0.14
0.50
0.00
1.00
Reject Rate
Run Simulation
To Stage 1 - Initiation
To Stage 3 - Technical Review


Stage 3 - Technical and HSE Review
1: Technical and HSE Review
2: Backlog 3
50.00
25.00
0.00
1.00
92.00
183.00
274.00
365.00
Graph 3 (Technical & HSE Review)
Days
12:15 PM Mon, Dec 11, 2000
To Main
there are any problems with the design or implementation plans.
Again, the work is modeled as a conveyor, with a Possion distribution.
Run Simulation
To Stage 2 - Development
To Stage 4 - Authorization


Stage 4 - Authorization
1: Approval
2: Temp Changes
3: Backlog 4
50.00
25.00
0.00
1.00
92.00
183.00
274.00
365.00
Graph 4 (Stage 4 - Authorization)
Days
12:16 PM Mon, Dec 11, 2000
To Main
Using the average of 7% of the changes being temporary - a leakage is created to fill a stock marked temporary. A buffer for the permanent changes identified as backlog is created.
Run Simulation
To Stage 3 - Technical & HSE Review
To Stage 5 - Acceptance


Stage 5 - End User Acceptance
1: Work in Progress
2: Startup
60.00
30.00
0.00
1.00
92.00
183.00
274.00
365.00
Graph 5 (End User Acceptance)
Days
12:16 PM Mon, Dec 11, 2000
To Main
The End User Acceptance Stage is characterized by training, pre-startup safety review, manual updating as well as the
Run Simulation
To Stage 4 - Authorization
To Stage 6 - Documentation


Stage 6 - Documentation & Records
1: Document Revision
2: Completed Changes
3: Change Clock
300.00
1.00
150.00
0.00
0.00
-1.00
1.00
92.00
183.00
274.00
365.00
Graph 6 (Stage 6 - Documentation)
Days
12:15 PM Mon, Dec 11, 2000
To Main
The Documentation Stage is a critical step. Without proper and controlled documentations - changes could be taking place on top of changes leading to uncontrolled
Run Simulation
To Model
To Stage 5 - Acceptance