A Complex Situational Management Application
Employing Expert Systems
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ABSTRACT

We are developing a complex situational management application for non-steady state events. The domain in which we are working is polyester film base manufacturing. The complex situational management application is an expert system that monitors the non-steady state events and assists the human operators with the event tasks. This application currently implements three event checklists and system monitoring logic that represent standard operating procedures for large, complex, film base machines.

1. INTRODUCTION

The development of complex monitoring systems for environments, such as nuclear power plants and chemical processing, is not new (see Rasmussen and Rich). Such systems require that human operators monitor the system to ensure proper safety and production levels. The amount of information presented to the human operator in such systems is very large and can require complex cognitive processing to deduce current conditions and required actions. Such systems rely upon the human operators to act as problem solvers. The system we are developing is intended to assist the human operators in solving problems and completing tasks while tailoring the system to the particular environment. As Vicente states, “We cannot expect workers to play the role of adaptive problem solvers in a consistent and reliable fashion unless we provide them with information support that is tailored to the demands of this challenging role.”

Eastman Kodak Company produces polyester film base used in the motion picture industry, as well as many other industries. The process of producing such film requires many stages from base manufacturing, to sensitizing, to finishing. This paper concentrates on the base manufacturing that creates the initial film base. The process employed for creating this film base is a complex system that requires many operators, mechanics, and engineers to monitor and maintain the process. The ultimate goal for Eastman Kodak Company is to produce as much product while incurring the least amount of waste and costs in order to increase the company’s income.

The complex monitoring systems that have been used to monitor and control this process were developed under what could be considered a traditional software development cycle. The application requires that a software engineer update and maintain the system. The system does not permit the software to be updated and immediately used on the machine during production. The entire machine must be shut down and taken off line in order to incorporate new changes. Additionally, it then becomes difficult to test the new implementations, as the machine is not in a running state. Traditional systems are usually a “one size fits all” application. When a “one size fits all” application is used on multiple machines that are different physically and mechanically, it can become difficult for the human operators to maintain the system and optimize production.

Our work has concentrated on the development of an expert system to be used for film base manufacturing. The idea is to provide a complex monitoring system that can be easily modified and customized to each production machine by the actual experts (the engineers) at any time. This paper will concentrate on the generic system we have developed for non-steady state events.

This paper provides a description of the machine and process. We review the goals of the system development as well as the implementation of the non-steady state event monitoring. We discuss the results of this work and complete the paper with our conclusions.

2. POLYESTER FILM BASE PRODUCTION

Eastman Kodak Company has produced polyester film base for almost 45 years. Currently, production of this film base occurs at four plants worldwide. The process employed to produce the film base is a complex chemical process. The process requires an extrusion process to melt and filter the polyester before it can be placed onto a casting wheel. The film then proceeds through a process of coating, stretching, and cooling before it is wound into rolls.

The machines used for this process are typically over one hundred yards long and two to three stories tall. The machines are required to run at temperatures approaching 540° Fahrenheit (F) and the film moves through the
machines at speeds that approach 350 feet per minute. The machines have various sensors placed throughout the machine with some machines containing over 1500 sensory points, which the human operators monitor. These machines run 24 hours a day, 365 days a year.

Each machine is similar in concept, but no two machines are identical. The machines were not built at the same time. There are a few machines built from the same blue print but even these machines are not identical. Over the years, new mechanics have been added and original parts have been replaced, additionally, engineers have made changes to specific machines.

Each machine has a crew of production operators. Additionally, each shift has a crew of mechanics responsible for all the machines at a particular location. The production and mechanical crews work in 12-hour shifts for two days followed by two nights. Finally, each machine has a machine engineer who typically works Monday through Friday eight hours a day. Each machine engineer is on call and may receive calls or be required to come into the plant during the night or on weekends. Each group of users possesses slightly different knowledge of the system. The production operators work on the machine, but do not fully understand the system mechanics. The mechanics maintain the machine, but do not fully understand the process. The machine engineer is considered the expert regarding all aspects of the machine.

A constant goal for almost any corporation is to make an income from its production activities. This goal is no different for polyester film base. Because it is extremely costly to make significant changes to these machines and even more costly to build new machines, the company’s goal is to increase production while reducing costs (i.e., waste).

The primary waste events have been found to occur during non-steady state events. Such events are categorized as heating of the machine from room temperature or heating the machine from a standby condition required for maintenance activities.

Non-steady state events are particularly complicated because the system must be heated at a certain rate in order to ensure that the machine sections are properly heated and that the polyester heats appropriately without overheating. If the polyester is not hot enough waste will be produced. Additionally, if the polyester is overheated the result can be hours of waste production. The worst possible outcome is shutting down the machine requiring the event to be started again from the beginning.

3. SYSTEM DEVELOPMENT GOALS

There are four primary goals established for the system development. This section discusses each of these goals.

The first goal is to reduce the machine downtime and waste production, leading to reduced production costs and increased profits.

The second goal is to provide process consistency between crew shifts on a single machine, across the machines at a single location, and across all machines worldwide. It has been found that as a crew change occurs, often important information is not communicated between the two crews. Additionally, whereas the machines are similar but not identical, and the operators may be moved from one machine to another, there is a need to provide a consistent monitoring capability across the machines that accommodated the machine’s difference while assisting the operators with their tasks. Finally, providing consistency across machines worldwide permits the various locations to easily work together to solve common problems.

The third goal is to provide complex monitoring of the process that is beyond the existing control system capabilities. It is well known that vigilance in complex systems can be a problem, particularly when the operator has many tasks to complete at one time. Additionally, as the operator’s workload increases, the operator’s cognitive abilities may be hampered. The idea is to develop intelligent monitoring so that the human operators will be relieved of some complex cognitive monitoring tasks.

The fourth goal is to provide a flexible tool that can be customized to each machine on an as needed basis by the machine expert, the machine engineer. Traditional systems typically require a software engineer to develop the code that implements the expert knowledge. Our goal is to provide a tool that can easily be modified by the machine engineers. The machine engineers are the domain experts and are responsible for the operation of their machines. They have also expressed a desire to have more control over the software employed on their machine.

4. THE COMPLEX MONITORING SOFTWARE

A team of individuals reviewed many off-the-shelf expert system development products for use in this work. The decision was to use the G2 expert system and G2 Diagnostic Assistant (GDA) products developed by Gensym Corporation.
The G2 product is object oriented and relies on the GDA visual logic blocks to capture the domain expertise. The product also provides a proprietary English like programming language. The available visual logic blocks cover the basic requirements and include process control capabilities. Additionally, G2 experts are able to define their own logic blocks. The logic blocks are connected via either logic or data paths. This tool enables the machine engineers to easily develop the logic they require for monitoring and detecting problems on their machines. Additionally, the visual logic implementation provides the production operators and mechanics with a tool that they can visually review when there is an issue with the system.

The G2 developers are primarily responsible for defining the initial object classes and object icons. An example of an object class and icon is provided in Fig. 1. This figure represents a drying section of the machine. The icons are developed based upon the actual machine drawings. This particular section presents the film as it moves through the machine. The intent is to provide an accurate representation of the machine to the human operators to improve their capability to understand and use the system.

![Figure 1](image)

**Figure 1.** A representation of a drying section in a polyester film base production machine.

The G2 developers are also responsible for developing capabilities such as the checklist capability discussed in Section 5 (a checklist example is available in Fig. 4). This capability is not provided directly by the Gensys products and has been primarily developed by Reynolds.

The machine engineers are responsible for providing the expert knowledge by developing the visual logic representations. Figure 2 represents a single piece of logic developed by the machine engineers. The G2 tool permits the data to be passed from an object (similar to the object in Fig. 1) to the logic. The data is passed through a data display block then through a data inhibit block to the low value observation block. The data inhibit block allows the developer to control when this particular piece of logic will be evaluated. When the low observation block concludes a true value and the remaining conditions are also true, then an alarm is presented to the operator by the conclusion block. The machine engineer provides the text for the alarm message. The advice for handling this alarm is also defined in the alarm block by the machine engineer. G2 builds a text explanation of why the alarm occurred based upon this logic and also permits the human operator to view the logic for a specific alarm.

We have found that the G2 tool meets our needs as a flexible expert system development tool that can be "programmed" by the machine engineers. It is true that software developers are required to do complex system development, but the machine engineers manage the expert knowledge. One limitation of G2 is that it is an interpreted language and therefore executes slower than other available tools. Since we do not use the system to directly control the machines, this is not an issue at this time.

![Figure 2](image)

**Figure 2.** A simple piece of logic implemented by the machine engineers.

5. NON-STEADY STATE EVENTS

The non-steady state events are the primary focus of this paper. Such events include heating the machines from room temperatures (~70°F) to run temperature (~540°F) or heating the machine to run temperatures from standby conditions (~480°F). There are three types of non-steady state events and it is these events that are the most complicated. It is during these events that human errors occur most frequent.

Non-steady state events can last anywhere from 48 hours to 72 hours depending upon the particular event. An event may incur over seven crew shift changes and possibly four different crews.

The non-steady state events occur infrequently, perhaps 12 times a year for a particular machine. This implies that it is possible that the time between events for a single crew may be a few months, if not a year.

Standard Operating Procedures (SOPs) have been used for years to lead the operators through such events. The SOPs across machines are similar in the steps that are required, but vary depending upon the specifics of the particular machine they have been developed for.
The primary goal for the non-steady state events is to translate the SOPs into an application that would assist the operators with the task completion while attempting to provide consistency across events, crews, machines, and plants. This goal includes developing an interactive SOP and relieving the operator's cognitive task load by automating complex monitoring tasks in the system.

The first steps for implementing such events is to review the SOPs with the machine engineers, production operators, and mechanics. The purpose of this activity is to understand what the production operators and mechanics actually do to complete a step, ensure that the steps are meaningful, add needed steps, delete unnecessary steps, and identify steps that the expert system can monitor.

Once the SOPs are appropriately updated and released, the task becomes one of creating an interactive, dynamic, and intelligent checklist that implements the particular SOP. This work typically occurs with the machine engineer (sometimes with the assistance of a G2 expert) creating the checklist logic. Figure 3 displays a section of the checklist logic definition. Each block contains a particular step or message that will appear in the checklist. Each block may also include logic that the checklist will verify when the operator indicates that the step is completed. Additionally, each block may also execute a procedure to complete various tasks, such as prompting the operators for further information.

Our most complex checklist consists of approximately 300 steps and contains over 50 decision points that dynamically change the checklist presented to the operators. The decision points are based upon information gathered from the machine, as well as information gathered from the operators.

![Figure 3. A section of the logic that implements the checklist steps.](image)

In addition to defining the checklist logic, each checklist also has an associated set of monitoring logic. The monitoring logic may be enabled the entire time that the checklist is running, or certain sections may be enabled or disabled based upon the current state of the machine. The monitoring logic is one of the most critical sections of this work. For example, in the past, the operators have been required to record a list of sensor values every hour based upon which non-steady state event they are executing. This list of sensor values can range from approximately 40 to over 100. It has been found that even though the data is recorded, the operators do not always recognize critical problems over time. The monitoring logic provides the smart monitoring for these types of activities. It also relieves the operators of a task that they find tiresome. Fig. 2 is an example of the logic that can be used for such monitoring.

An important aspect of the monitoring logic is that not only is the logic watching for problems and providing alarms when a problem occurs, the monitoring logic provides further information for the operators. The monitoring logic is created such that each alarm has an associated piece of advice. This advice instructs the operator on exactly how to handle and correct the system for a particular alarm. This capability has streamlined the manner in which situations are handled by the operators. Additionally, the G2 software automatically develops an explanation stating why a particular alarm occurred. This explanation is developed from the logic that triggered the alarm. The operators may also look directly at the visual logic for a particular alarm.

Another important aspect of the monitoring logic is the capability to control the steps the operators are allowed to execute at a particular time. In the past, such events have been controlled by time rather than the actual state of the machine. Using the G2 system, the event is actually controlled by the condition of the machine. This is very important when attempting to heat the machine to a particular temperature and avoid waste.

Once a prototype checklist and monitoring logic have been developed, they are reviewed by a team that includes all users. Revisions are made based upon the comments and feedback, typically during the meeting. Once the checklist has reached an acceptable level, it is then used on the machine. Revisions typically continue but decline as the checklist is used more frequently. It should be noted that the flexibility of the development environment permits rapid changes to the checklists.

The operators and mechanics are requested to enter any comments while using the checklists. All comments are reviewed by the machine engineer, production operators, and mechanics in the week following the event. Any required changes are immediately applied to the checklist.

An example section of a checklist is provided in Fig. 4. The operator knows which steps are currently available to execute based upon the green arrows pointing to particular steps. If the operator attempts to complete any other step by clicking on the step, then the step is not executed. Anytime that the system verifies a measure is not as it
should be, the operator is informed. The operator is given the option of correcting the problem and retrying the step, ignoring the problem and continuing with the checklist, or aborting the checklist. If the operator chooses to ignore and continue a checklist, he or she is required to enter an explanation regarding the reason for continuing.

| North Filter Heat-up |
| Filter installation and resin line connection complete per MSP 30 |
| Verify clean side flush valve is open and nitrogen purge ON at 100 SCFH. |
| Leak testing of Dowtherm lines complete |
| Valves positioned per MSP 373. |
| Vaporizer level is between 10 and 15 in. |
| System evacuated for 4 hours (minimum of 2 hours). |
| Vaporizer temperature at 580 degrees. |

**Figure 4.** An example checklist for a non-steady state event.

### 6. RESULTS

There are many results associated with this work. The initial result, prior to any checklist development, has been a much better understanding of the machine and the process by the machine engineer, production operators, and mechanics. Another result is that the SOPs for each machine have undergone severe scrutiny and the results are more accurate, and less ambiguous SOPs. These two results developed from the task of reviewing and meticulously updating the SOPs for the machines. In one instance, it was thought that an important valve was a particular size and therefore, provide a certain flow rate. When the data indicated differently, it was determined that when the valve had been replaced a few years earlier, the original valve size was no longer available. The valve was replaced with the next larger size. This resulted in a behavior that was different on this particular machine from what was expected based upon the other machines and prior knowledge.

When similar but slightly different temperature behaviors on a machine may indicate a particular problem, the tool provides a similar alarm message and usually similar problem resolution across the machines.

Tied into the second result is the reduction of steps that the production operators are required to complete for a particular event. Because the tool is intelligent and constantly monitoring the event activities, the operator’s monitoring tasks are reduced. For instance, since the tool monitors the system temperatures and looks for particular patterns, the operators are no longer required to record all relevant temperatures each hour and look for problem patterns. Such capabilities free up the operators to work on other tasks. This is particularly important when the crew is shorthanded and two people are required to complete the work of three or four people.

An additional result tied to the second result, is the machine engineer’s ability to easily customize the application for their machine. Traditional software applications do not provide such capabilities. With a few hours of training the machine engineers are capable of developing complicated logic for monitoring their machines.

The ability of the machine engineers to develop their own logic has resulted in monitoring logic that monitors the system during events, but also controls the steps to be completed in the checklist. They have also easily extended the complex monitoring provided by the machine control system to provide more specific and intelligent alarming capabilities.

A third result is the reduction in waste produced during non-steady state events. This reduction in waste has been recognized on the machine running the non-steady state event tool for the last year. The reduction is waste represents a substantial savings to the division and Eastman Kodak Company.

At a time when corporations are looking for better, faster, cheaper ways to make products, the results in this section are very important to the production of polyester film base at Eastman Kodak Company.

### 7. CONCLUSIONS

This paper presents a high-level description of the complex chemical process required to produce polyester film base. The paper also describes the software used to develop the expert system for this application. We provide a high-level description of the non-steady state events encountered in this process and provide a description and demonstration of the expert tool developed for such events.
We also state the goals of this work. The described results show that we have been able to attain each of the goals listed in Section 3. Specifically, the G2 tool has proven to be sufficiently flexible so that the machine engineers can use it to customize the non-steady state event checklists and monitoring logic for their particular machine.

The non-steady state event checklists and monitoring logic have extended the complex monitoring capabilities of the existing machine control systems. This has resulted in a more accurate representation of the knowledge in the system, as well as providing detailed, intelligent, and useful information to the production operators and mechanics.

The need to provide consistency between crew shifts on a single machine, as well as across the machines at a single location for non-steady state events has been met through the development of the checklists and monitoring logic. We are currently in the process of sharing the capability across the various polyester film base plants worldwide.

Finally and potentially most importantly, it has been found that the use of the checklists and monitoring logic during the non-steady state events has reduced the amount of waste produced during and immediately after such events. This has resulted in a significant financial savings to the division and the company.

We continue to work on implementing this capability across all the polyester film base production machines worldwide. We are currently expanding the capability of the system to monitor steady state production.

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