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DEVELOPMENT OF A SIMULATION MODEL FOR AN ARMY CHEMICAL MUNITION DISPOSAL FACILITY

Michael A. Berger
Jiuyi Hua
Paul T. Otis
Katrina S. Werpetinski

Mitretek Systems, Inc.
7525 Colshire Drive
McLean, VA, 22102-7400, U.S.A.

Vincent F. Johnston

U.S. Army
Chemical Demilitarization
Attn: SFAE-CD-CO-O
Aberdeen Proving Ground, MD 21010-5401, U.S.A.

ABSTRACT

The U.S. Army is in the process of disposing of its stockpile of obsolete chemical weapons. A simulation model has been developed to help identify facility operational strategies that may increase the number of munitions or the quantity of chemical agent processed over an extended period of time. It is also used to assess the potential effects of proposed plant modifications and alternative process configurations on plant performance, schedule, and operating costs prior to their implementation. A new customized graphical user interface to the simulation model has been developed to overcome software limitations and enhance the model system. This allows more rapid and complete assessments by a variety of users at different facilities.

1 INTRODUCTION

1.1 Background

In order to comply with the international Chemical Weapons Convention (CWC), U.S. Army is scheduled to destroy (demilitarize) its stockpile of obsolete chemical warfare munitions and agents by the year 2007. These munitions are stored at different locations in the continental U.S. and on Johnston Island (JI), which is located in the Pacific Ocean approximately 800 miles southwest of Hawaii. The stockpile consists of nerve and blister agents contained in bulk items (e.g., bombs and ton containers), rockets, projectiles, and land mines. The Army has developed a disposal process involving munitions disassembly, agent incineration, and thermal decontamination of metal parts. A first-generation full-scale disposal facility, the Johnston Atoll Chemical Agent Disposal System (JACADS), has been operating on JI for over five years. A second-generation facility, the Tooele Chemical Agent Disposal Facility (TOCDF), is also in operation near Tooele, Utah. Additional chemical agent disposal facility plants are being constructed at other chemical munitions stockpile locations.

1.2 Objectives

Mitretek is working with the Army to conduct assessments of the JACADS and TOCDF operations with respect to reliability, availability, and maintainability (RAM). A simulation model of a chemical munitions disposal facility has been developed to assist in the RAM assessment efforts. The model is used as one of the analytical tools to identify facility operational strategies that may increase the number of munitions or the quantity of agent processed over an extended time. It is also used to assess the potential effects that proposed plant modifications and alternative process configurations would have on plant performance, schedule, and operating costs prior to their implementation.

Future plans include the installation of the completed model system at each operational site to allow the rapid completion of relevant modeling studies. Significant development has been performed to allow the model system to be successfully used by analysts not generally familiar with simulation modeling or the software tool utilized.

1.3 Paper Organization

This paper describes efforts in the development and use of the simulation model. Section 2 of this paper provides a brief description of the chemical munitions disposal process. Section 3 describes the model and Section 4 discusses the newly developed user interface. The model input data are discussed briefly in Section 5. Section 6 summarizes verification and validation results and Section 7 presents sample results of ongoing assessments. The conclusions of this paper are presented in Section 8.

2 PROCESS DESCRIPTION

The demilitarization process involves the reverse assembly, or disassembly, of the chemical munitions into their separate explosive, chemical agent, and structural components. Specialized incinerators separately process the materials and components: the deactivation furnace (DFS), which burns explosives and decontaminates associated metal parts (e.g., rocket pieces and projectile explosive components); the liquid incinerator (LIC), which burns the liquid agent and spent decontamination solution; and the metal parts furnace (MPF), which decontaminates drained projectile and bulk item metal parts. Each incinerator has a primary chamber, a secondary chamber (afterburner), and a pollution abatement system (PAS). The primary chamber provides the temperature, oxidizing conditions, and residence time to achieve the desired destruction. The secondary chamber provides additional assurance that any residual organic vapors will be fully destroyed. The PAS is designed to reduce any pollutant emissions in the exhaust gas to below the levels established in the environmental permits prior to release.

The demilitarization process begins when pallets of chemical munitions packed in specialized containers are transported by truck from storage igloos to a handling building for temporary storage until needed. The munitions are then transferred to the unpack area of the munitions demilitarization building. A simplified process flow for projectile processing is shown in Figure 1. Projectiles are automatically transferred from the unpack area using a series of conveyors to one of two explosive containment rooms (ECRs), where a multi-station projectile/mortar disassembly machine (PMD) removes the explosive bursters and components. Following transfer to the munitions processing bay (MPB), three multi-station multipurpose demilitarization machines (MDMs), operating on two processing lines, access the agent reservoir and drain the liquid chemical agent. The agent is sent to the toxic cubicle holding tanks for subsequent destruction in one of two LICs. Trays of drained projectiles are transferred to the MPF for processing of residual agent heels and thermal decontamination of the munition bodies.

Rockets are drained of agent and sheared into pieces at rocket shear machines in the ECRs. Rocket debris is fed to the rotary kiln DFS for incineration and decontamination. For bulk munitions, holes are punched in the bulk item and the agent is drained at special stations in the MPB. The drained bulk item shells are then processed and decontaminated in the MPF.

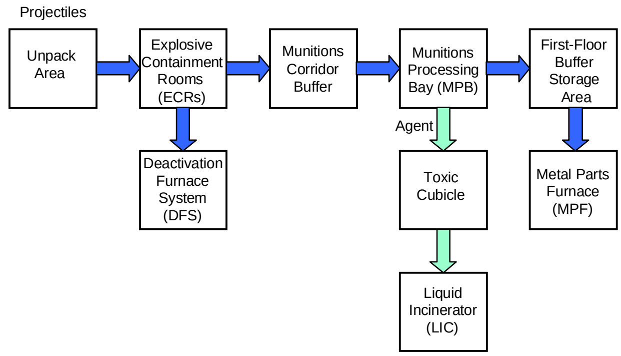

Figure 1: Simplified Flow of Projectile Processing

3 SIMULATION MODEL

Although the essential purpose of a chemical weapons demilitarization plant is disassembly and destruction, the plant is very similar to a general manufacturing facility. Methodologies developed during this project can be applied to similar modeling studies of more traditional manufacturing facilities.

The Army selected Deneb Robotics' QUeueing Event Simulation Tool (QUEST®) as the software to be used for the development of a plant simulation model. QUEST is a discrete-event simulation software package for modeling, visualization, and evaluation of manufacturing systems. Plant pieces of equipment are partially pre-defined and programmed according to their function as machines, conveyors, buffers, etc. Failure rates and repair times can be defined for applicable pieces of equipment. Output statistics are available to report the time that equipment was busy, blocked, idle, and under repair during a simulation run. (Barnes 1997)

Using QUEST, a dimensionally correct three-dimensional physical representation of the TOCDF plant, process equipment, and the different munitions has been developed. The TOCDF plant (see Figure 2) is modeled as a virtual factory, starting with the delivery of munitions and ending with the collection of waste for transfer off site. Areas modeled include the unpack area, ECRs (see Figure 3), MPB, and buffer storage areas. The transportation and disassembly equipment are modeled to a machine level, such as individual conveyors, blast gates, hoists, and stations of the demilitarization machines. The furnaces and PASs are modeled to a major end-item level. Munitions are processed and routed through the simulation according to specified operational times, speeds, and logic. Pieces of equipment fail and are repaired according to defined statistical distributions. Distributions are also specified for some cycle times to add additional realistic random variability to the model.

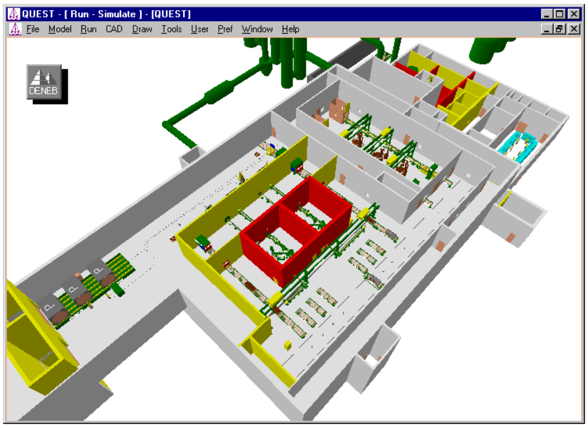

Figure 2: Overall View of Model Layout

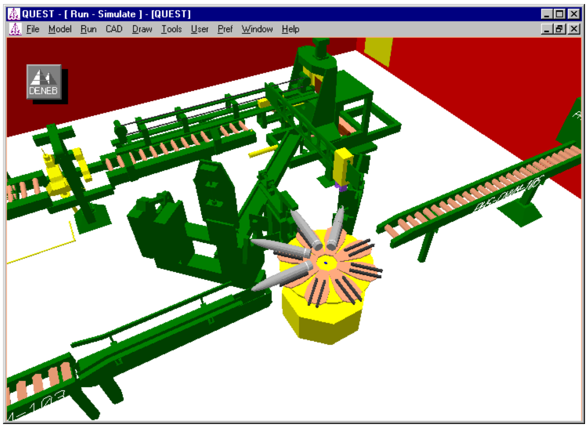

Figure 3: View of Explosive Containment Room

Animation may be used to observe the entire system while the simulation is running, which is useful in validating the plant processes. The model is run on high-end computers running Windows NT. The model was originally developed in QUEST Version 2 and was subsequently upgraded (a fairly significant effort) to Version 3 and then to Version 4.

4 GRAPHICAL USER INTERFACE DEVELOPMENT

Due to the complexity of the model and QUEST software limitations, the original model system was somewhat difficult to use and did not provide complete results for effective RAM assessment purposes. It was difficult for anyone other than an experienced QUEST user to run the simulation model and interpret the results. Using the standard QUEST interface, it was cumbersome to modify a model configuration, change the values of variables, perform complex series of runs, and analyze the output results. It was therefore necessary to develop a special graphical user interface (GUI) to the QUEST modeling software to enhance the TOCDF model system. This GUI allows more rapid and complete modeling runs and assessments by a variety of users. The GUI is needed to allow successful use of the model system when it is delivered to the operational sites.

The new GUI is coded in Microsoft® Visual Basic 6.0, which offers excellent GUI development capability, ease of manipulating database transactions, strong text string processing capability, and good potential for further upgrade. From a software structural perspective, the GUI contains three major components. The first component is the user interface, which exchanges the information between the user and the software. The second component contains all the pre-processing and post-processing functions including data parsing, generation of files of input parameters and specialized code needed to run QUEST, statistical computing and plotting, and archiving. The third component is a database constructed in Microsoft® Access to store the model input data and results.

The **Main Menu** window (see Figure 4) is the major gateway to access all the other features of the GUI. The **Main Menu** window contains buttons that allow the user to perform various tasks including (1) running QUEST quickly using default settings, (2) setting up a series of runs (session), (3) setting up or modifying data for a model, (4) performing run archive functions, and (5) generating defined reports.

Figure 4: GUI Main Menu Window

With the GUI, the simulation model can be run in two basic modes of operation: with or without animation. When the model is run in an animation mode, the user has access to the QUEST menu and button interface system so that the operation of the system can be viewed for validation or demonstration purposes. The user can move through the plant simulation, and pause and resume the model;

however, results cannot be saved to the archive database. For analytical studies and assessments, the model animation is turned off to maximize the running speed of the model. In this mode, the user cannot interact with QUEST while the model is running.

Selecting the **Set Session** button in the **Main Menu** window will open a window, as shown in Figure 5, for setting a simulation session. In the **Set Session** window, the number of simulation model runs to be made within that session is specified. By double-clicking a run listed in the list box, the simulation length and warm-up time can be edited. In addition, the number of replications of the same model (with different random number seeds) can be easily specified. The model uses ten random number streams (and a seed value for each stream) when selecting new failure, repair, and cycle times from defined statistical distributions.

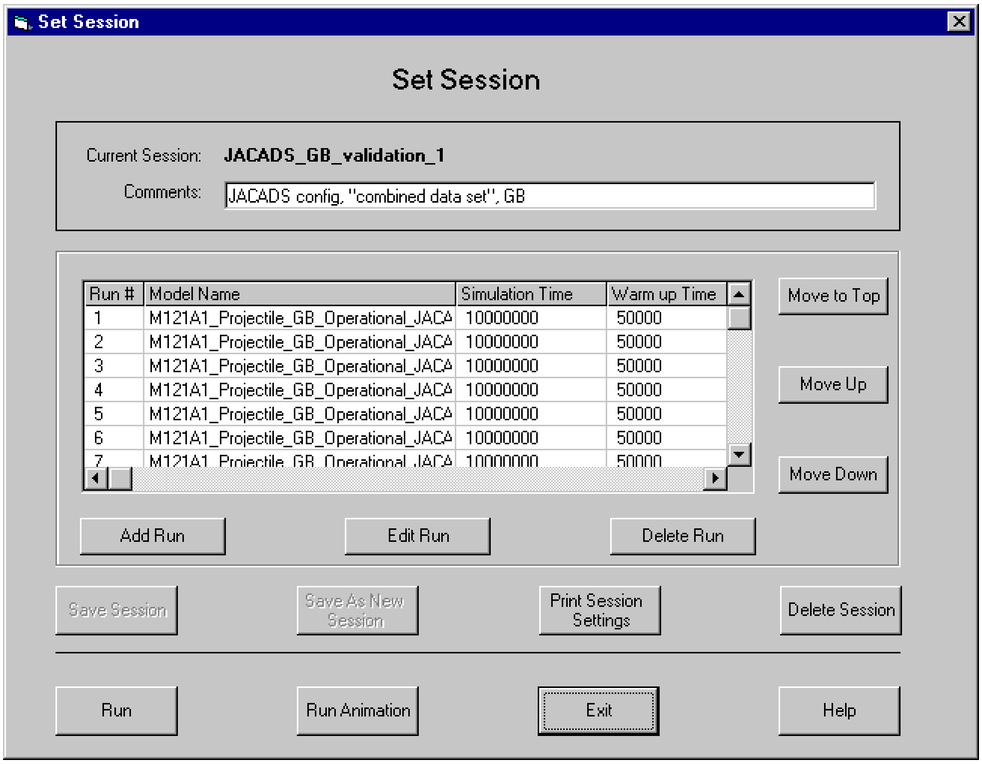

Figure 5: GUI Set Session Window

From the **Main Menu**, clicking the **Set Model** button opens a window (see Figure 6) to define and configure a model; this includes specifying munition and agent type and setting parameter values at the equipment level. The user-changeable variables are categorized into four groups: configurations, timing, conveyors, and failure groups. Over 300 variables within the model can be varied during modeling studies. The variables that appear in the windows (and their values) are specific to the base model, munition type, and agent type selected. The values can be reviewed and changed either individually or within tabular listings of multiple variables.

Archive and **Report** selections are also available from the **Main Menu**. **Archive** functions allow the saving and deleting of model output data. Informative output reports, not available as standard QUEST outputs, have been specially developed and can be accessed through the **Report** button. Tables of plant throughput rate, system availability, and buffer area utilization and plots of cumulative throughput and buffer area history can be automatically generated following a simulation run.

5 MODEL DEVELOPMENT AND DATA

Base models have been created (using either design or operational data) for default modeling runs and as the basis for modified models. Design data are obtained from facility design documentation. Most initial operational data have been obtained from JACADS because that facility has been in operation longer than TOCDF. Operational data are not always available for all model parameters; therefore,

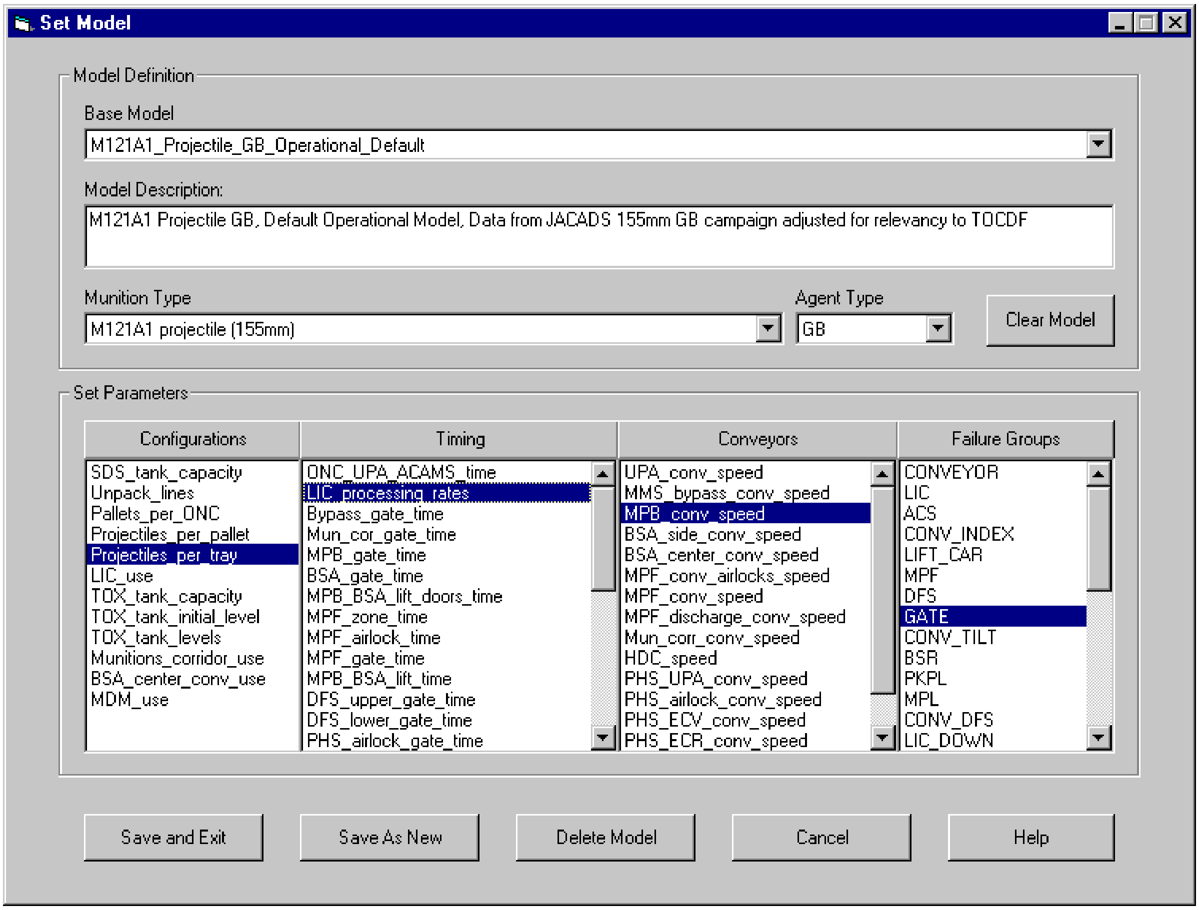

Figure 6: GUI Set Model Window

design data and engineering judgment are used as required to help create the operational models.

A methodology has been developed and applied for converting actual operational plant data to a form that can be used in the simulation model. The model requires two main types of equipment information: failure characteristics and cycle times. This information is obtained from a production/downtime database that is created by plant personnel for each munition campaign. The database contains an annotated chronological history of the changes in operational status of each major system throughout each day.

Mitretek analyzes this database to calculate applicable equipment mean time between failures (MTBF), mean cycles between failures (MCBF), mean time to restore (MTTR), and cycle time. The elapsed time for each major system is divided into different categories of time that detail whether the system is processing, waiting for feed (idle), failed, or undergoing scheduled downtime (e.g., preventive maintenance). Two additional categories indicate instances where the entire plant is not operating due to either a plant-wide failure or a deliberate plant shutdown. Scoring Conferences are held with Mitretek, Army operations, Army Materiel Systems Analysis Activity (AMSAA), and plant personnel to authenticate and score (classify and aggregate) the data for RAM assessment and modeling purposes.

System cycle times are calculated by examining the cumulative processing time for each system. Failure rates and repair time parameters are calculated using data from the system failed times and scheduled downtimes. Each failure event is identified as to which piece of equipment caused the system failure; scheduled downtime events are identified by the reason that processing was halted. Failures and downtimes are assigned to failure groups that combine similar types of failures for similar pieces of equipment or systems (e.g., conveyor failures or machine preventive maintenance).

For failure groups with sufficient numbers of failures, a statistical software package (Stat:Fit from Geer Mountain Software) is used to help determine the appropriate statistical distribution of the data. The distribution selection has been limited to exponential and lognormal distributions because they are frequently used in manufacturing modeling and are relatively simple to define and use. The exponential distribution is simple because it requires only an average (mean) value. One typical use of an exponential distribution is to represent machine times to failure (Law, 1996). A lognormal distribution requires the calculation of a standard deviation, as well as a mean value. One typical use of a lognormal distribution is to represent the time to perform a given task (Law and Kelton, 1991) such as equipment repair.

Analysis of the failure group data shows that the lognormal distribution is frequently the best fit, particularly for restore times. Most restore times are fairly short; however, a few are extremely long. Times between failures and cycles between failures for unscheduled failure groups usually fit lognormal distributions. Times between failures and cycles between failures for scheduled downtimes fit lognormal or exponential distributions.

6 VERIFICATION AND VALIDATION

The simulation model has undergone verification and validation (V&V) to ensure that it is suitable for use. Verification is the process of confirming that the model meets design requirements and performs as it is designed. Validation is the process of confirming that the model accurately replicates real operations (Williams 1998).

Verification includes running the model with estimated design parameters to determine if output results agree with design predictions. The model is run for 10,000,000 seconds; this simulates about four months of plant operations. Average throughput is calculated from ten model runs. The first 50,000 seconds of each run are considered a warm-up period, and no statistics are collected. Based on the design data, the model closely matches plant peak and average throughput for the munition types tested.

Validation consists of collecting and analyzing JACADS and TOCDF operational data, inputting the data into the model, and comparing the output from the model to the calculated throughput and availability from the munition campaign data. Validation is performed for each munition type as data become available from the plants. For projectile types studied, the model produces a throughput closely matching the actual observed throughput at the plant. The plant throughput is also within the range of stochastic throughputs produced by individual runs of the model. The system availability results from the model generally agree closely with availability calculated from the data. These results indicate that the assumptions used in developing the model are reasonable and the model can be used as an assessment tool.

7 SAMPLE RESULTS

The model is being used in support of RAM assessments for current and future campaigns at TOCDF and JACADS. Simulation model runs are being performed to study plant throughput and availability, as well as buffer area behavior. Throughput rates are used to estimate the campaign length needed to destroy specific types of munitions. Selected parameters are modified as part of sensitivity analyses to determine their effect on overall campaign length. Sample results from RAM assessments studying alternative processing scenarios are presented below. One effort examines the simultaneous processing of ton containers on one operational line and projectiles on the other line (i.e., complementary processing) at TOCDF. (Ton containers [TCs] are horizontal steel tanks approximately 8 ft long by 2.5 ft in diameter that hold less than 2,000 lb [1 ton] of liquid chemical agent.) Another assessment effort uses previous data from processing one type of projectile at JACADS to predict the plant campaign behavior when processing another type of projectile.

7.1 LIC Utilization

Information can be obtained concerning the utilization of the two LICs at TOCDF during each type of scenario or campaign. The status of each incinerator is tracked during the run and reported as: Failed, Idle, Processing decon, or Processing agent. Figure 7 shows the results for three operational scenarios: projectile processing, TC processing, and complementary processing. The bar for projectiles shows that the LICs are idle significant portions of time during a projectile campaign. For a TC campaign, the low LIC idle time, along with other information, indicates that the LICs are the bottleneck when processing TCs. One of the reasons complementary processing was developed was to try to more fully utilize the LICs. The chart shows that when complementary processing occurs, the LICs are idle an intermediate amount of the time.

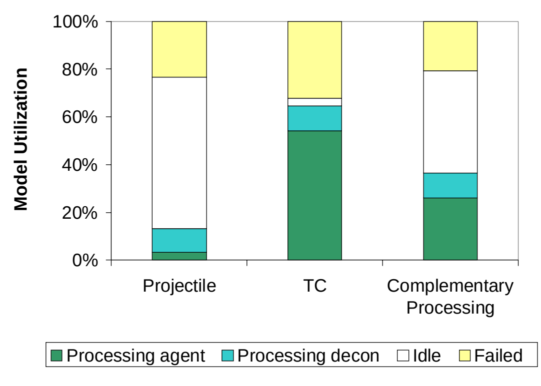

Figure 7: LIC Utilization During Complementary Processing

7.2 Buffer Area Analysis

Various complementary processing operational scenarios have been studied to help optimize buffer areas in the plant. Figure 8 shows a representative plot of the number of TCs on conveyors in the first-floor buffer storage area waiting to be fed to the MPF. For the scenario shown, there is a significant period of time where there are seven TCs (the maximum) buffered, indicating a potential bottleneck in the MPF. There could be several reasons that the buffer is full: the furnace could be (1) failed, (2) ramping temperature between munition types which are processed separately, (3) processing projectiles, or (4) processing TCs relatively slowly. Additional studies and analyses are then performed to further explore this system behavior.

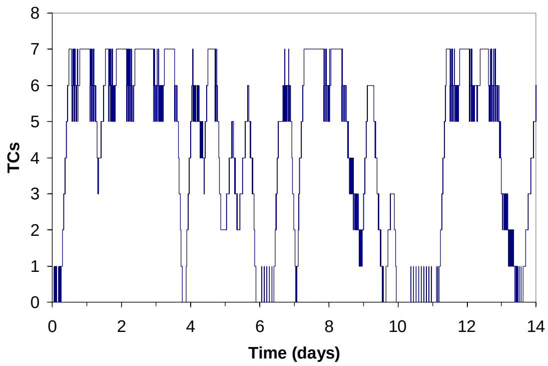

Figure 8: TCs in Buffer Storage Area

Other buffer areas have also been examined. Even though QUEST is a discrete event software package, it has been used to model the flow of liquid agent and other fluids. Consequently, the behavior of the agent holding tank liquid level is examined to study this buffer between agent draining and agent incineration.

7.3 Campaign Length

A characteristic munition throughput is obtained for each campaign by averaging the overall throughput rate over multiple runs. Campaign lengths are determined using the characteristic throughput rate and the number of stockpiled munitions that need to be destroyed. A model is often run with various data sets to determine how different assumptions concerning operational data will affect the predicted campaign length. Figure 9 shows how the campaign length could increase over a baseline level if certain process enhancements (e.g., resulting in reduced MTTRs or cycle times) are not successfully implemented for an upcoming campaign. Upper and lower bounds obtained from modeling runs provide indications on the variability possible for campaign length. Sensitivity analyses are often performed by selectively increasing/decreasing failure rates, repair times, or cycle times. These analyses determine which aspects of a process are rate-limiting for plant throughput (and thus campaign length). The Army and the plant operator can then focus their improvement and monitoring efforts in these critical areas in an attempt to shorten the schedule and reduce overall cost.

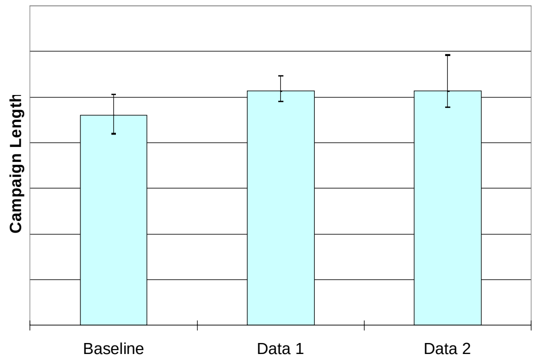

Figure 9: Campaign Lengths for Data Sets

8 CONCLUSIONS

Simulation modeling is helping the Army best plan the current and future destruction of the stockpile of obsolete chemical munitions. A powerful simulation model has been developed to simulate the processing of projectiles, rockets, and bulk items in various munition campaigns. Modeling efforts study plant throughput, system availability, and buffer area behavior and can predict munition campaign length. By varying model parameters, the effects of proposed changes to a process or configuration can be easily investigated. This allows proposed modifications to be prioritized with regard to their benefit in reducing the overall destruction program cost and schedule.

The model of a chemical munitions disposal facility has been developed in QUEST. However, the model is very large and its complexity previously required a user to be knowledgeable about special QUEST constructs in order to fully perform and analyze various modeling variations and statistical studies. A new GUI has been developed to combine the strengths of QUEST with the detailed requirements of chemical munition disposal facility analysis. The GUI offers the following advantages to users at the facility sites:

- The user of the model will no longer need QUEST programming skills in order to make variations to model parameters.
- Multiple model runs (including multiple replications of the same model) can be easily performed.
- Built-in report generating options are provided that will save effort in extracting and computing results from QUEST output files.

- The GUI archiving feature significantly enhances the user's capability of managing the simulation-related data.

Although the essential purpose of a chemical weapons demilitarization plant is disassembly and destruction, the plant is very similar to a general manufacturing facility. Methodologies developed during this project (e.g., QUEST model development, GUI development, data treatment, and analysis procedures) can be applied to similar modeling studies of more traditional manufacturing facilities.

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AUTHOR BIOGRAPHIES

MICHAEL A. BERGER is a Principal Staff Engineer in the Center for Science and Technology of Mitretek Systems. He specializes in simulation modeling, performance assessments, and technology evaluations. Previous modeling efforts have included manufacturing plants, transportable military hospitals, and biomass gasification facilities. He received a B.S. in Chemical Engineering from Carnegie Mellon University in 1982 and a M.Ch.E. in Chemical Engineering from the University of Delaware in 1984.

JIUYI HUA is a Lead Systems Engineer in the Center for Science and Technology of Mitretek Systems. He specializes in systems modeling, artificial intelligence and software development. Previous modeling efforts have included manufacturing plants and transportation system modeling. He received a Ph.D. in Civil Engineering from the University of Delaware in 1995.

VINCENT F. JOHNSTON is a Captain in the United States Army Acquisition Corps. He is currently assigned to the Project Manager for Chemical Stockpile Disposal as the Associate Project Manager for the Umatilla Chemical Agent Disposal Facility. His previous assignment was as the Modeling and Simulation Officer for the Project Manager for Chemical Stockpile Disposal. He received a B.S. in Biology from the University of Tampa in 1990.

PAUL T. OTIS is a Lead Staff Engineer in the Center for Science and Technology of Mitretek Systems. He specializes in simulation modeling, performance assessments, and technology evaluations. Previous experience includes process design, plant operations, economic evaluations of manufacturing facilities, regulatory analysis, and pollution prevention program implementation. He received a B.S. in Chemical Engineering from Texas A&M University in 1980 and a Ph.D. in Industrial and Systems Engineering from Virginia Tech in 1999.

KATRINA S. WERPETINSKI is a Lead Staff Engineer in the Center for Science and Technology of Mitretek Systems. Her work at Mitretek has involved developing a chemical demilitarization facility process model and performing reliability, availability, and maintainability studies using the model. She received a B.S. in Chemical Engineering from Michigan State University in 1990 and a Ph.D. in the same from the University of Massachusetts at Amherst in 1996.