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Discrete Event Simulation in Manufacturing Environments: The Waste Isolation Pilot Plant

Benjamin Thomas Burnette
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Benjamin Thomas Burnette entitled "Discrete Event Simulation in Manufacturing Environments: The Waste Isolation Pilot Plant." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

Reid Kress, Major Professor

We have read this thesis and recommend its acceptance:

William R. Hamel, Gary V. Smith

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Gary V. Smith

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Accepted for the Council:

Anne Mayhew

Vice Provost and Dean of Graduate Studies

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DISCRETE EVENT SIMULATION IN MANUFACTURING ENVIRONMENTS: THE WASTE ISOLATION PILOT PLANT

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Benjamin Thomas Burnette
December 2002

DEDICATION

This thesis is dedicated to my Lord and Savior, Jesus Christ, because of the love and grace He shows me each day. I would also like to dedicate it to my loving and supportive wife who constantly encourages me to move beyond my perceived limitations.

ABSTRACT

The purpose of this thesis was to construct a discrete event model of the waste handling activities inside of the Waste Isolation Pilot Plant (WIPP) in order to examine "what-if" scenarios designed to increase the rate at which waste is disposed.

The discrete event modeling software EXTEND was chosen by Sandia National Laboratories (Sandia) because of its ease of use, flexibility, ability to customize, and low cost. Historical and observed data were used to construct, verify, and validate the resulting model. Verification ensures that the model works as programmed, and validation ensures the real world system is truly being modeled to some degree of accuracy. After determining that the system was modeled correctly, scenarios were evaluated to determine what could increase the waste throughput, and tests were preformed to determine to what resources within the model throughput are most sensitive.

Results from the model include a two month run generated by a historical shipping schedule and data collected from the scenarios examined, such as increasing shipments, adding equipment, and varying the available labor pools. Resulting in a recommendation to add a second shift

From the results it is concluded that the model does successfully simulate the current system at WIPP, and it offers insightful data regarding system modifications.

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INTRODUCTION

Begun by the Department of Energy (DOE) in 1983, the Waste Isolation Pilot Plant (WIPP) is designed to receive and dispose of transuranic waste. This waste resides at several generator sites across the United States as shown in Figure 1.

Due the amount of waste and the planned "life" of this project, efforts will be made at WIPP to accelerate the amount of waste of which it disposes within the next 15 to 20 years. This report offers recommendations for increasing the rate of disposal at WIPP and evaluates these options using discrete event simulation.

Figure 1: Locations of Generator Sites [19]

1 BACKGROUND

1.1 WIPP

The Waste Isolation Pilot Plant (WIPP), located 26 miles southeast of Carlsbad, NM, is a permanent disposal site for defense generated transuranic radioactive waste or TRU waste. Transuranic waste consists of clothing, tools, rags, residues, debris and other such items contaminated with small amounts of radioactive elements -- mostly plutonium. These elements are radioactive, manmade, and have an atomic number greater than uranium -- thus transuranic (beyond uranium) [15].

WIPP began receiving TRU waste from the generator sites in March of 1999 with plans to accept as many as 37,000 shipments over the next 35 years [14]. There are 25 of these sites which have generated and stored radioactive waste, some since the 1940's. After the waste is received at WIPP, it is transported 2,150 ft below ground to its disposal in an ancient, stable salt formation as shown in Figure 2.

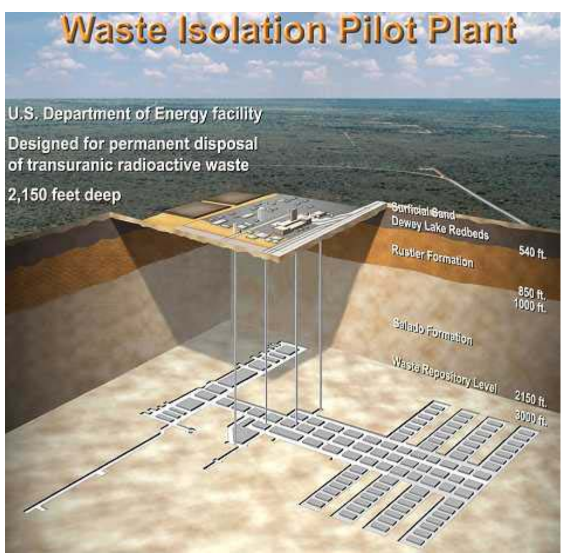

Figure 2: WIPP Overview [20]

Stable geological formations were recommended as disposal sites by the National Academy of Sciences in the 1950's. In the 1960's, the government searched for an appropriate location which led to testing in southeastern New Mexico in the 1970's. The facility was finally constructed in the 1980's [15].

Salt was the disposal material of choice for several reasons [16]:

- Salt deposits are often found in areas with little earthquake activity
- Salt deposits reveal the absence of flowing fresh water which could move waste to the surface
- Salt is relatively easy to mine
- Rock salt heals its own fractures because of its plastic quality which means the salt formations will progressively move to fill in the mined areas and seal the radioactive waste from the environment

In an effort to aid the DOE in accelerating its clean up goals, Sandia National Laboratories (Sandia) has utilized several simulation models to represent characterization, transportation and the disposal processes of TRU waste [14].

1.2 Computer Simulation

According to Banks, "Simulation is the imitation of the operation of a real-world process or system over time," although simulation is not limited only to the time domain [1]. Other disciplines simulate processes over cycles, in the frequency domain, with respect to position, and other ranges. The goal in simulating a system is to generate an artificial

history, infer system behaviors based on that history, and perform analyses in a cost efficient manner as compared to testing in the real-world environment. These inferences allow the modelers to make educated decisions about system design and modification. Overall, simulation is used to evaluate potential changes to a system and study systems in the design state [1].

In general there are two types of simulations for systems: static and dynamic. Static or Monte Carlo simulation represents a system at a particular point in time. It deals with modeling the probability of a particular scenario result. Dynamic simulations, however, look at a system as it changes over time [1]. An example would be the activity at a carwash over one week.

Within dynamic simulations, there are continuous and discrete model categories. A continuous system is "one in which the state variables change continuously over time." Banks uses a classic example to illustrate this idea: a dam and the head of water changing behind it. A discrete system, however, "is one in which the state variables change only at a discrete set of points in time." The carwash example mentioned earlier would fall into this category. The number of cars at the carwash changes at discrete points in time: as a car arrives, completes the washing, and leaves. Although it is rare for a system to be completely continuous or discrete, often one characteristic will predominate [9]. This dominate characteristic defines the system's primary behavior. Higher order effects are governed by the non-dominant behaviors, however, the main response of the system can be related to the dominate characteristic. Since many systems-related questions and subsequent decisions can

be answered by investigating the dominant behaviors, this is sufficient.

In Kress' paper "Discrete Event Simulation of Manufacturing Systems," the discrete event approach proves very insightful in many situations. One example is a manufacturing facility that has difficulty answering questions such as the overall effect on a system due to a single change. This difficulty is due largely to the many complex variables involved within each system. Discrete Event simulation is offered as one avenue of evaluating this question. Several examples are used in Kress' paper to demonstrate the effectiveness of Discrete Event simulation, with results compared to and validated by hand calculations. Discrete Event simulation is shown to be an effective tool in modeling several kinds of different systems (i.e., manufacturing systems and robotic systems) [6].

Within discrete event, there are two subcategories or methods of modeling: Supply Chain and object based analysis. Supply chain models focus on the path that items take as they flow through the system. This type of modeling has proven very valuable in answering questions such as, "How full should a truck be before it is dispatched?" Waiting until it is full could delay delivery, but partial load shipments increases freight cost per unit [11]. In perhaps a more complicated situation, supply chain modeling has been employed to analyze the issues in merging two food manufacturers of similar size. Two particular companies were able to use the simulation to determine how to size existing distribution centers and accommodate the new products in their systems [12]. Supply chain models have also been combined with production models in order to provide essential contextual information about the model interactions [10].

These production models bring into discussion the other discrete event method of modeling, object based analysis. In this approach, the focus is on what happens to an item as it flows through the system. Law and Kelton describe this system below [7]:

> *"…a simulated system is considered to consist of objects (e.g., an entity or a server) that interact with each other as the simulation evolves over through time. There may be several instances of certain object types (e.g., entities) present concurrently during the execution of a simulation. Objects contain data and have methods. Data describe the state of an object at a particular point in time, while methods describe the actions that the object is capable of performing. The data for a particular object instance and only be changed by its own methods. Other object instances (of the same or of different types) can only view its data. This is called encapsulation"* (227).

Although discrete event (DE) modeling is recognized as a valuable tool, it's often difficult to move into adopting the technology. As with most technologies, the timing and method of delivery is very important. Several issues should be considered before implementation, such as software selection, management buy in, model usability, who should create the model, who will use the model, and reasons for building a model in the first place. It is noted that DE models can be used in several areas such as decision making, training and education, design, shipping and scheduling. Careful planning can lead to successfully using this valuable management and engineering tool [5].

Although implementation may be a challenge, rewards have been experienced by

many. A snapshot of success examples in DE modeling includes: QUALCOMM, Lindsey Olive Company and an automotive power train manufacturer. Their successes are summarized below.

In order to stay ahead in the digital wireless field, QUALCOMM needed to streamline its equipment manufacturing and improve inventory control. Analysis began on spreadsheets, but these quickly became complicated and hard to modify. EXTEND modeling software was chosen by QUALCOMM because it offered a good balance between flexibility and customization. Currently seven models have been created for different parts of the facility. Industrial engineers have validated the models and then sent them to manufacturing engineers who use them while designing. These models have helped QUALCOMM determine line sizing, capital equipment choices, and personnel scheduling [3]. While QUALCOMM used modeling to help streamline its production, Lindsey Olive Company uses it to aid in increasing production.

Expecting an increase in sales, Lindsay Olive Company decided to increase production, and in order to do this efficiently, Lindsay used SDI Industry™, powered by EXTEND™, to determine which measures could increase the plant capacity enough to handle the production volume increase. In order to verify and validate the models, engineers analyzed input, output, and model logic. The study's output was a report that could be compared to the plant's annual report. Results of the study allowed engineers and managers to understand how the system would respond to increases in production. It also proved useful in evaluating scheduling issues and where capital investments should be made [8].

Similarly to Lindsey Olive, a powertrain assembly plant used discrete event modeling to understand the effects of changing production systems.

Due to the many complexities within a powertrain assembly plant, simulation is often employed in the design and implementation of production systems. Contributing to the complexity are random variables such as process and schedule variations, worker availability, and equipment performance. Specifically, this project focused on the plant testing areas due to their need for careful attention and design. The users found discrete event simulation to be very helpful in designing and optimizing the arrangement and number of test stands, and they have concluded that all issues in test stand design can be solved using simulation. The simulation also proved valuable in saving time and expense by testing PLC logic [4].

However, as mentioned earlier not all models are wholly discrete, as the examples above, or continuous, and some models take advantage of both features. Law reminds that "since some systems are neither completely discrete nor completely continuous, the need may arise to construct a model with both aspects of discrete event and continuous simulation" (p. 89). An example would be the SALT MINING model recently created for the WIPP mining process. This model combines discrete and continuous elements with the aid of sophisticated software. Discrete event elements include shifts, failures, and the change in resource availability. Key continuous elements are mining rates, truck hauling rates, hoisting rates, and above ground truck rates. The interaction of these two aspects of modeling can show insightful information. Several simulating packages will allow

integration of discrete and continuous components. Some of these packages are Arena, Awesim, and Extend [7].

2 APPROACH

2.1 Simulation Steps

Simulation modeling is typically characterized by a multiple-step process. The model goal and requirements must be stated, approach defined, form and use of the results must be anticipated and conceptualized, and possible conclusions envisioned prior to the beginning the initial coding. The simulation approach is outlined in Figure 3. The following is a summary of the step descriptions listed by Banks on pages 14 through 18 [1].

Problem formulation: All simulation studies should begin with a clear problem statement. Although not shown in the figure, often this statement must go through reformulations as the study progresses.

Setting of objectives and overall project plan: Objectives indicate the questions to be answered by the study. These often change in content and quantity as the simulation takes shape. “Customers” often expand their requests once they see the breadth of capability offered by the simulation

Model conceptualization: A model need only capture the essence of the real system. The ability to abstract key elements of a problem is the art behind conceptualization and is essential for good model construction. It is best if it focuses on only those processes that influence the behaviors being studied. An initial model should be basic in complexity and become more sophisticated as needed.

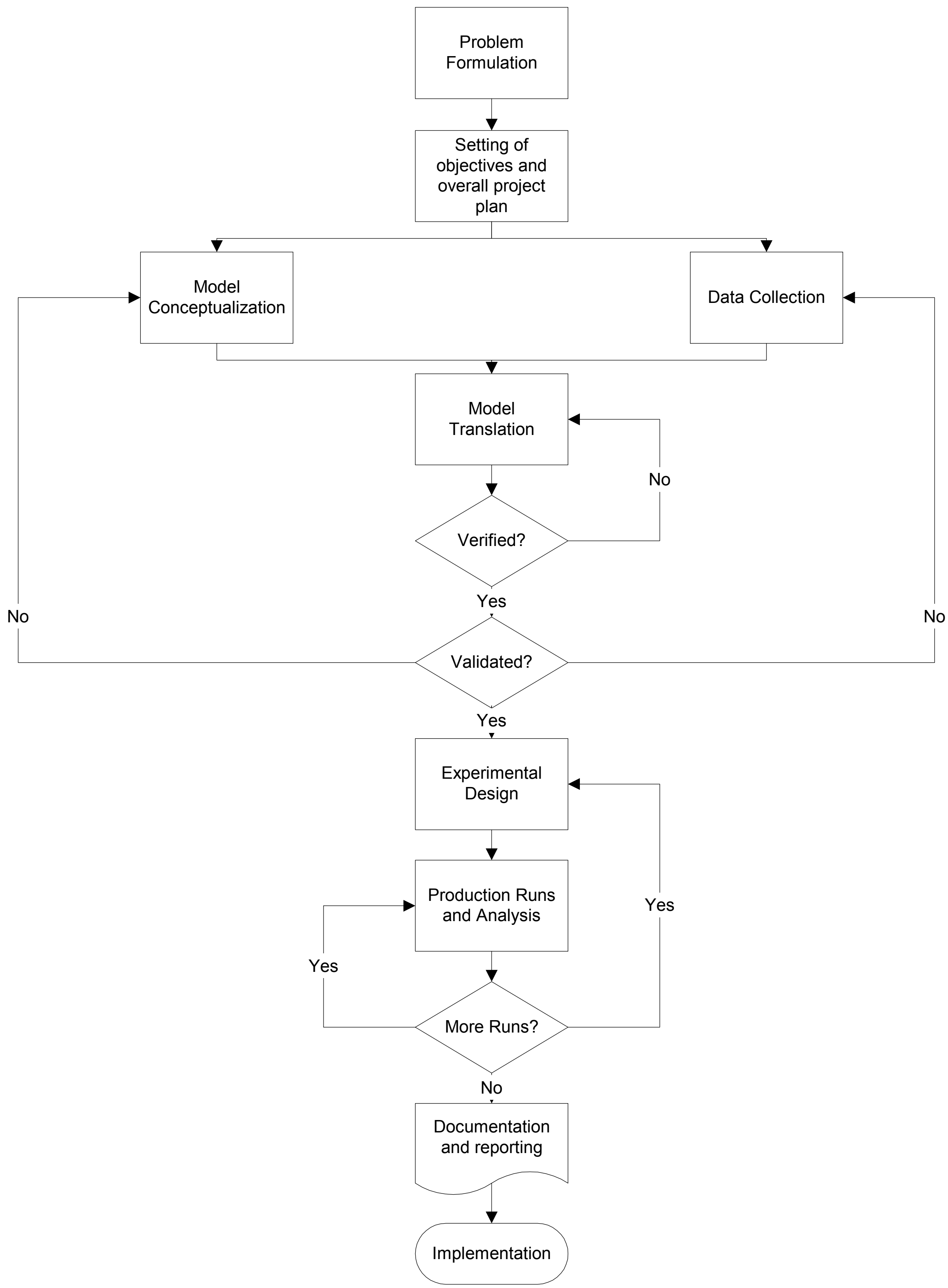

Figure 3: Simulation Steps [1]

Data collection: Data collection and model construction have constant interaction. The study objectives will determine the data needed to be collected and often dictates the form of the data and required accuracy. This data can be used to run the model or validate it.

Model translation: This step encompasses moving the data into a computer recognizable format and includes choosing the appropriate software tool and programming the model.

Verification: This is the debugging step for the program. The step in which the programmer asks "is this model running properly?" It often requires the development of small test routines to verify logic and functionality. These test results are critical to efficient and robust model building and will be saved as part of the documentation.

Validation: To validate a model is to determine if it is an accurate representation of the system being studied. This step is critical and must involve subject matter experts as well as the simulation modeler.

Experimental design: The experimental designs are the different alternatives to be evaluated by the model. In general some of these experiments must be simple in nature so that the simulation modeler can understand the behavior of the modeled system.

Production runs and analysis: Production runs and their analysis are the estimated performance of the alternatives evaluated in the model. These are the sought-after results.

More runs: Analysis of the previous runs can often lead to a need for more model runs and/or changes to the model. This can lead to a loop back into the requirements stage.

Documentation and reporting: There are two types of documentation involved in modeling, program and progress. Program documentation allows other analysts to understand program logic and will provide confidence to users and policy makers by showing the verification runs on the test routines. Progress documentation is the chronology of work performed on the model including key decisions, accomplishments, change requests, and other important items.

Implementation: Implementation of the study's findings is often dependent upon the degree of which the end user is involved in the model's construction. It also depends on the effort placed into the model, user interface for the input and output as well as the end users sophistication.

2.2 Process Description

This next section will break down the individual steps of the Contact Handled (CH) waste process. CH waste is the low grade radioactive material that is the focus of this model. The following will describe in more detail the individual steps shown in Figure 4.

Waste enters the WIPP site through the main gate where a brief inspection is performed. Regulation allows only one truck in the gate at a time, and this process usually takes about 10 minutes. Preliminary paperwork is checked by the Transportation Engineer

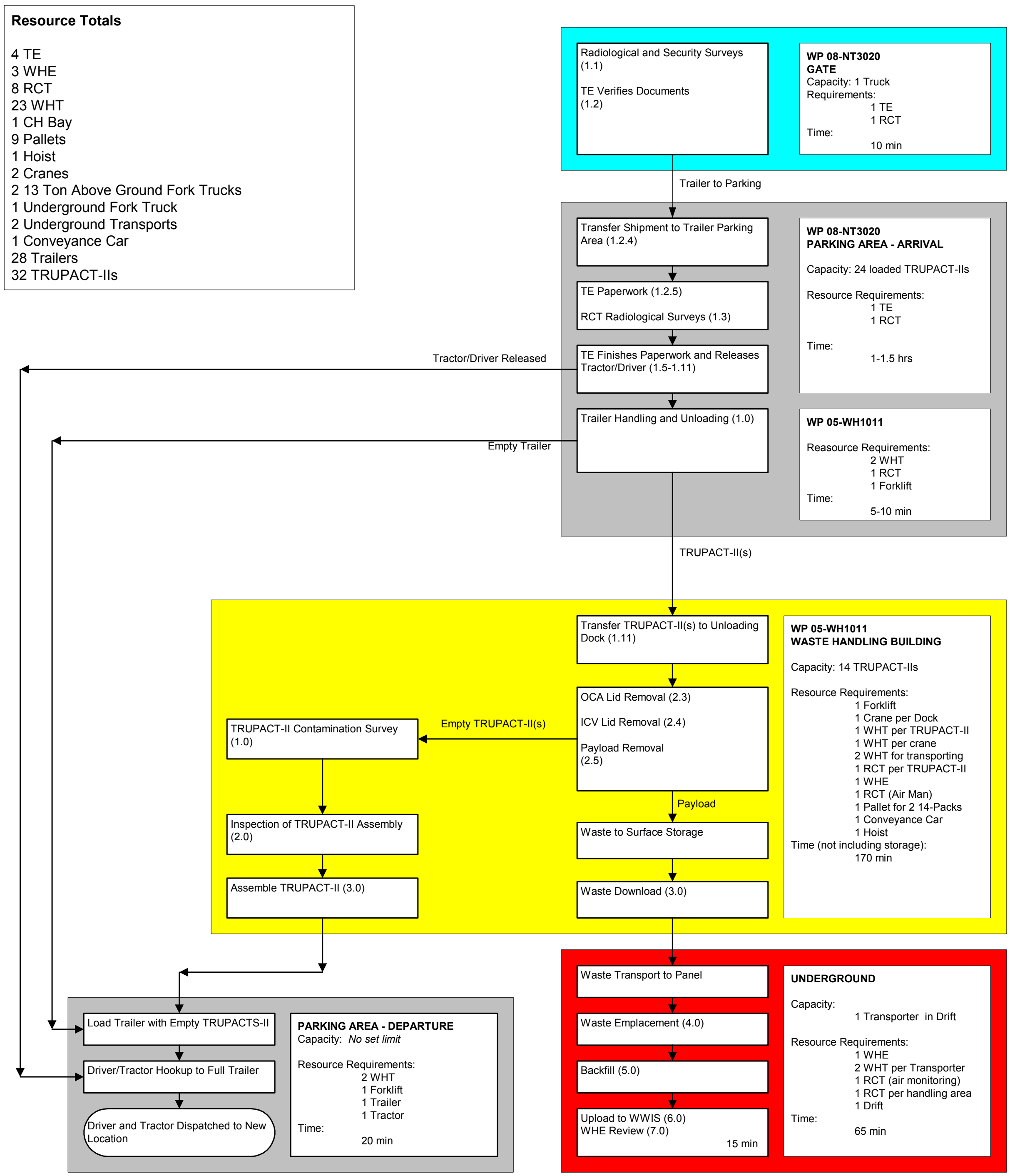

Figure 4: CH Waste Process Overview

(TE); and a Radiation Control Technician (RCT) swipes the outside of the TRUPACT-IIs for radiation levels. The TRUPACT-II is the containment vessel in which the radioactive waste is transported and is shown in Figure 5. After completing this inspection, the truck moves the trailer into the parking area.

Inside the parking area, the RCT continues the inspection process, shown in Figure 6, while the TE completes the required documentation. If no discrepancies are found in the documentation, the TE releases the truck and driver. This process usually lasts one to one and a half hours (as reported by the TE).

If the remaining trailer is to be unloaded, a total of 3 men are required, two of the Waste Handling Technicians (WHTs) and one RCT. The WHTs must be trained up to the level of Floor Yard and Emplacement (FYE). This is the second level of WHT training and involves basically transporting the waste above and below ground. The first level, Training, only allows operations not directly dealing with waste, and the third level, Dock Handler, includes all dock operations and the abilities of the FYEs. One of the WHTs will operate the forklift and one will act as a guide as shown in Figure 7. The RCT is a regulation requirement during the movement of all waste.

Due to regulations, the waste is moved one TRUPACT-II at a time into the Waste Handling Building (WHB) through the airlock. The capacity inside is 11 payloads, the contents of a TRUPACT-II. Once inside the WHB, the TRUPACT-II is directly placed into one of the available dock positions as shown in Figure 8.

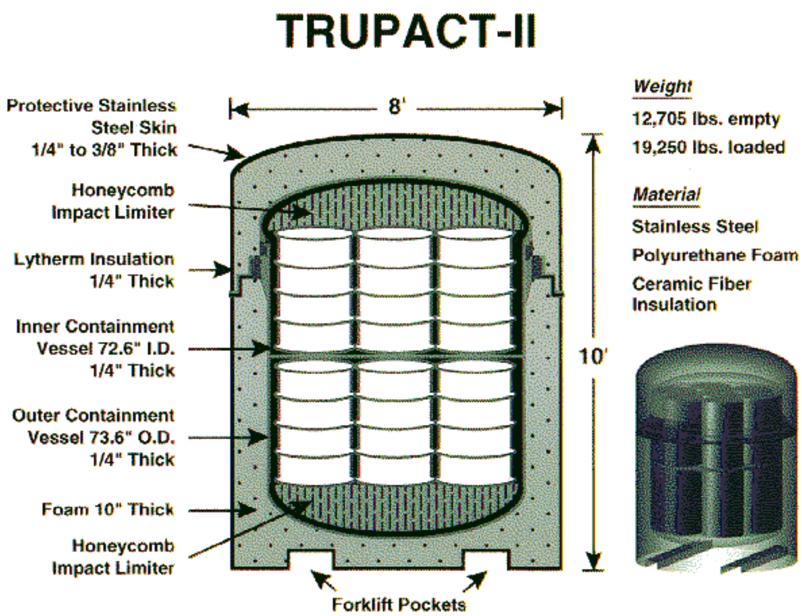

Figure 5: TRUPACT-II Diagram [18]

Figure 6: Radiation Swipes [18]

Figure 7: Trailer Unloading [18]

Figure 8: Dock Loading [18]

For the dock operations, two WHTs trained to the level of Dock Handlers are required per TRUPACT-II along with one RCT. The average time for 2 TRUPACT-IIs inside the dock is approximately 2 hours. Once in position, preparation is made to remove the Outer Containment Assembly (OCA) lid of the TRUPACT-II. The OCA lid is lifted by crane and placed into storage beside the dock, and an RCT takes a swipe of the Inner Containment Vessel (ICV) lid.

When the ICV lid is lifted, a “hood” is placed over the lid, and it drapes down to the containment vessel. An air sample is then taken from inside the vessel as shown in Figure 9. If the radiation level is acceptable, the hood is removed, the ICV lid is also placed in storage, and preparations are made to lift the payload out of the TRUPACT-II. Payload removal is shown in Figure 10.

Swipes are taken by the RCT on the surface of the payloads. These payloads are usually two packs of seven 50 gallon drums in a honeycomb formation stacked on top of each other. They are also known as a 14 – Pack. Long-leg attachments are used with crane in order to reach the base of the payload and lock into the TRUPACT-II Pallet. This is a circular pallet that supports all payloads during transport. The crane then lifts the payload out of the ICV container as in Figure 10.

Once lifted from the containment vessel, the payload is placed onto a Facility Pallet. The capacity of a Facility pallet is two payloads. Once a Facility Pallet is filled, it is taken to surface storage where it is kept until it is to be downloaded.

Figure 9: Vent Hood Test [18]

Figure 10: Payload Removal [18]

The transport to surface storage is completed by two WHTs, a fork truck, and a RCT. According to code, a payload removed form the TRUPACT-II must be moved to surface storage before a shift ends with or without filling the Facility Pallet. However, open TRUPACT-IIs containing payloads may be left mid-process at the shift's end. Processing time for two TRUPACT-IIs in one dock usually takes two hours.

The empty TRUPACT-II remaining in the dock will be cleaned, reassembled with a TRUPACT-II Pallet inside, and prepared for reassignment. The empty TRUPACT-II is then transported to outside storage with a fork truck by two WHTs of FYE training. TRUPACT-IIs are taken from this storage area and loaded onto trailers awaiting deployment for the next shipment.

The next step is to prepare the waste for downloading into the WIPP mine. Two WHTs and one RCT load the Facility Pallet onto the conveyance car with a fork truck as shown in Figure 11. This unit moves the Facility Pallet onto the Hoist where it is then transported underground.

Once underground, the Facility Pallet is placed onto the Transport as shown in Figure 12. Two WHTs of FYE training level are required per Transport, and one RCT must also accompany the Transporter during the trip to the emplacement site. Transportation time is about 15 minutes.

Figure 11: Conveyance Car Loading [18]

Figure 12: Underground Transport Loading [18]

At the emplacement site, a separate RCT will perform swipe tests to ensure that no damage has occurred to the payloads during transport.

The WHTs move the payloads off the Facility Pallet with a modified fork lift, as shown in Figure 13, and transport the payload to an emplacement stack, shown in Figure 14. Packing is then placed on top of finished stacks by the WHTs, and payload information is uploaded to the computer system by an RCT. Emplacement takes about 35 minutes. Finally, the Facility Pallet and TRUPACT-II Pallets are returned to the surface for reuse.

Figure 13: Underground Transport Unloading [18]

Figure 14: Disposal Site [18]

2.3 Problem Statement

The purpose of this thesis was to construct a discrete event model of the waste handling activities inside of the Waste Isolation Pilot Plant (WIPP) with the software package Extend in order to find bottlenecks and examine “what-if” scenarios for various system changes, such as increasing incoming shipments, varying labor pools, and increasing available resources.

This work was not supervised by the WIPP Quality Assurance program.

2.4 Model Creation

Model Structure

The model is comprised of multiple levels of hierarchical blocks or H-blocks. These blocks contain the code which executes the model operations. Code is generated by connecting graphical icons. A custom code, MODL, is behind each of the iconic blocks. On the surface of the model, pictured in Figure 15, H-blocks can be seen that represent the major steps in the waste handling process. These steps are Gate & Unload, East and West Docks, Surface Storage, Hoist Operations, and Out-Bound Truck operations.

Shifts

Shift blocks “[generate] a schedule over time which can be used to change the capacity of other blocks in the model. Shifts can be either be ON/OFF or represented by a number” [2]. The following is a discussion on the use of SHIFT Blocks with resource pools.

The personnel shift blocks determine how many people will be available for a given

day and what hours they will be available. Each of the personnel groups have a separate shift block which is connected in series to a master shift block. This master block, the "Day Shift,' provides the hours that all personnel are available, 6 A.M. to 4 P.M. Many complexities can be incorporated into the shifts by connecting the blocks in series.

The Hoist is also managed by a combination of shift blocks. The "Hoist Week" shift keeps the Hoist "On" at all times except Wednesday from 12 A.M. to 11:30 A.M. to account for weekly maintenance. The "Hoist Day" shift allows the Hoist to operate every day from 7 A.M. until 3:45 P.M. for waste operations, which does not include "man trips".

Finally, the 13 ton Fork Truck resource is controlled by a shift block that allows two fork trucks to be available from 6 A.M. to 4 P.M. and simulates charging in the "off" hours.

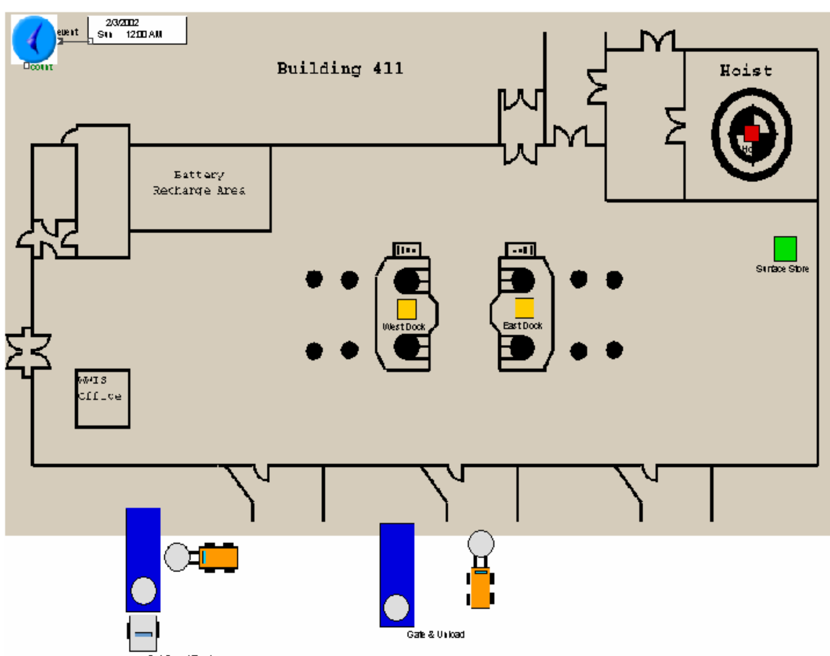

Figure 15: Model Surface

Resources

Resource pool blocks as defined by the EXTEND manual are blocks that "hold resource pool units to be used in a simulation. These units limit the capacity of a section of a model" [2]. Resource blocks are organized in this model into the categories of manpower, movers and miscellaneous.

Gate and Unloading Block

- A scheduling block determines when and how many trucks will arrive.
- An attribute is then assigned to the entity as it enters the model which indicates the model-time. This will be used to determine how long processes take.
- The entity enters the "Gate/Parking" H-Block and takes one resource from the Parking Lot and Gate resource pools.
- There is then a separate time delay for the security survey inside the parking area, and the Gate resource is released.
- The entity is then split among two different paths: the truck and trailer. The truck and driver move to a holding queue until needed, and the trailer is moved on to be split into the assumed shipment of 3 TRUPACTs.
- The time to move from the gate to outside storage is calculated.
- The entities then call the resource pool "WHB" or Waste Handling Building in order to reserve a space inside.
- A "Parking" resource is released to its pool before the TRUPACT is moved by fork truck operations into one of the open dock positions. Fork truck operations for CH

waste consist of one 13-ton fork truck, two WHTs of FYE training or higher, one RCT, and the route that will be used during transportation.

- The time delay for unloading the trailer and moving the TRUPACT to the docks is implemented, and the resources used for movement are released.
- The elapsed time the TRUPACT spends in outside storage plus its transportation time to the dock position is also calculated.
- The TRUPACT is the positioned in one of the available docks.

Dock Operations

- A space on the dock is reserved by calling on one of the two dock positions on either the East or West Dock.
- The personnel needed for Dock operations are assigned to the TRUPACT-II. This includes 2 WHT-DOCK and 1 RCT.
- The machine block then delays the TRUPACT for 90 minutes.
- The TRUPACT-II and payload are separated.
- The TRUPACT-II is cleaned, and a new TRUPACT Pallet is placed inside.
- All dock resources are released including personnel and the dock position.
- The empty TRUPACT-II is moved outside the Waste Handling Building.
- The payload moves on to the Surface Storage Block.
- All resources called on in dock operation are released.

Surface Storage

- Two payloads from the docks are batched together on one Facility Pallet.

- Resources needed for fork truck operations are called upon to move the Facility Pallet from the dock to surface storage.
- The associated time delay is accounted.
- Resources are released.
- The elapsed time is calculated for starting the process at the docks to moving the payloads into surface storage.
- Once the determined number of facility pallets is collected, they are then released to be moved underground.
- Resources needed for fork truck operations are called upon to move the facility pallet to the hoist and are released.
- The elapsed time is calculated for a facility pallet entering surface storage until it reaches the hoist.
- The WHB resource is released to its pool for the 2 TRUPACTs leaving the waste handling building and moving to the hoist operations.

Hoist Download Operations

- A “Gate” keeps more than two full facility pallets from being underground at one time since there are only 2 waste transporters.
- As a full facility pallet enters the “Hoist” H-Block it calls on the hoist resource pool, is delayed for travel time, and then releases the hoist resource to its pool.

Underground Operations

- Several pools are called upon to transport the facility pallet to the emplacement site. These include: 1 WHE, 2 WHT of at least FYE training, 1 RCT, and 1 Drift, which is the path traveled from the hoist to the emplacement site.
- A time delay is implemented for the associated travel. This delay is constant now, but in the future could vary as the room and panel location changes.
- The Drift is released.
- A time delay is implemented for the emplacement operations.
- The Drift resource is called upon again and the associated time delay is implemented.
- All personnel associated with the transport of that pallet and the Drift are released to their associated resource pools.

Hoist Upload Operations

- The empty pallet enters the Hoist H-Block and calls upon the "Hoist" resource pool.
- The associated time delay is implemented and the Hoist resource is released.

Final Waste Operations

- The facility pallets are released to their pool, and the TRUPACT pallets are un-batched and three different entities are released.
- This path terminates with an exit

Out-Bound Truck Operation

- A Gate block only allows one empty TRUPACT to be transported at one time to the outside storage.
- The transportation block calls on the associated resources for movement of an empty TRUPACT, incorporates the time delay, and releases the resources to their respective pools.
- The “MTOutside Store” is a holding queue for empty TRUPACTS until they are needed for loading onto outbound trailers.
- The load trailer block calls on the same resources required for the movement of an empty TRUPACT, incorporates a time delay for loading a single TRUPACT onto a trailer, and releases the resources to their respective pools.
- The following block combines three TRUPACTS with one truck/driver.
- The Gate resource is then called upon, a time delay in the gate is imposed, the Gate resource is released, and the loaded truck leaves the model.

Model Verification

As stated before, the verification step is ensuring that the program is working as one would expect or could be called the debugging process. This was done by methodically testing each subsection of the model with simple test routines that exercised the intended logic. Some of these tests included item conservation and zeroing out labor pools. In item conservation 10 TRUPACTS-II’s are input in the system which resulted in 5 facility pallets worth of waste being emplaced (note that a facility pallet carries two TRUPACT-II’s worth of waste). The other test mentioned, zeroing out labor pools, ensures that “tasks” inside the

model cannot be performed without the needed labor pools. For example, the Fork Truck pool was set to zero and the model was no longer able to move waste.

It is also important to ensure that resource pools are conserved. This is done by coding the model to pause if the resource pools begin to have more items available than the initial number given which would indicate that the model is spontaneously generating resources.

2.5 Model Validation

A detailed flow chart of the CH process was created by summarizing the multiple technical procedures that describe in depth the steps taken in disposing of CH waste. Once created, this flow chart was overviewed by Sandia National Laboratories (Appendix). It was used as a starting point for developing the model in EXTEND™.

Spreadsheets of actual processing times were combined with processing data generated by the model to create graphs that compare the two. If the graphs matched closely (within an error margin of 10%), the system was considered to be modeled accurately.

The WIPP model was calibrated with data from the February waste-handling log. The waste-handling log is a record of the processing times (beginning and ending) for each TRUPACT-II processed through the WIPP facility. The February data was entered into an EXCEL spreadsheet. It provides the date and time specific steps in the waste handling process began for each TRUPACT-II throughout the month. Calibration included modifying

the delay times for activities and logic for downloading.

The calibrated model was graphed against actual data contained in the waste handling log with EXCEL. In an attempt to model the decision to download waste, six different cases were evaluated, batching one, two, three, four, five, and a variable batch of facility pallets in the surface storage area. A linear fit was used to compare the data, and errors were calculated for each of the Hoist "batching" cases. The closest match of emplacement times, using a linear fit, is the case of batching four facility pallets then releasing each for download. After calibration a full two months of historical data was used compared against using the "batch four" logic

Anomalous data from the waste handling log was omitted. It is assumed that some of the data was erroneous in recording keeping or waste handling process. These were not considered since they add little value to the overall system.

2.6 Data Used by the Model

Randomness

In order to add more realistic features to the system model, randomness was introduced in some of the runs. The time delays inside the dock were chosen to incorporate this change because of the long processing time. The model of dock operations began as several sequential steps with associated time delays. These measurements came from direct measurement of only a couple of runs. Later in model creation it was determined that the historical data from the waste handling log would provide better statistical data for

introducing randomness into the model.

Using a months worth of data, a statistical distribution was determined using STATFIT2. The distribution of the data is log normal. This distribution, shown in Figure 16, is appropriate because the majority of the time there will be an average of “x” minutes spent on a particular event. Rarely will an activity be completed quicker than average because some things will always take a certain amount of time no matter how efficiently the rest of the process is running. The log normal distribution also reveals that sometimes, more frequently than the previous situation, a process will take longer than the average.

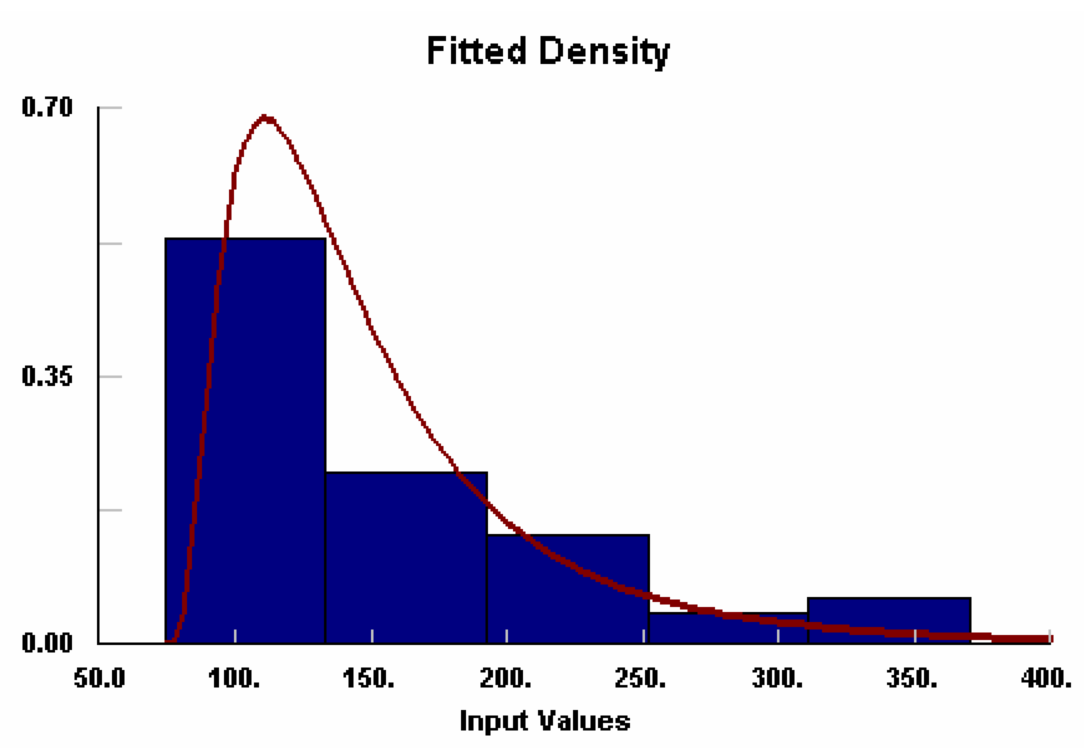

Figure 16: Log Normal Distribution

3 RESULTS

3.1 Calibration and Validation Results with February 2002 Historical Data

One of the first steps after the initial development of a model is to validate its performance against a historical set of data. This is not always possible, however in the case of WIPP, excellent data exist for validation. For this effort, February and March 2002 data sets were selected.

Figures 17 and 18 show the model time a TRUPACT-II arrived in the model and the time it entered into the surface storage area, respectively, compared to the actual time a TRUPACT entered each area. Upon inspection, the arrival time matches exactly. This is expected since the model is being catalyzed by historical data and no processing steps have been introduced yet. There should be no error at this point. This figure merely serves the purpose of verification.

Figure 18 shows that as the model has progressed to the surface storage area some errors have been introduced, but the general trend of the data is still the same. It seems that the major discrepancies are differed by a single shift or about 16 hours. This is likely due to choice at the end of a shift whether or not to move payloads from dock positions to Surface Storage. Regulation states that a payload inside a TRUPACT can remain at the dock position even after the close of a shift.

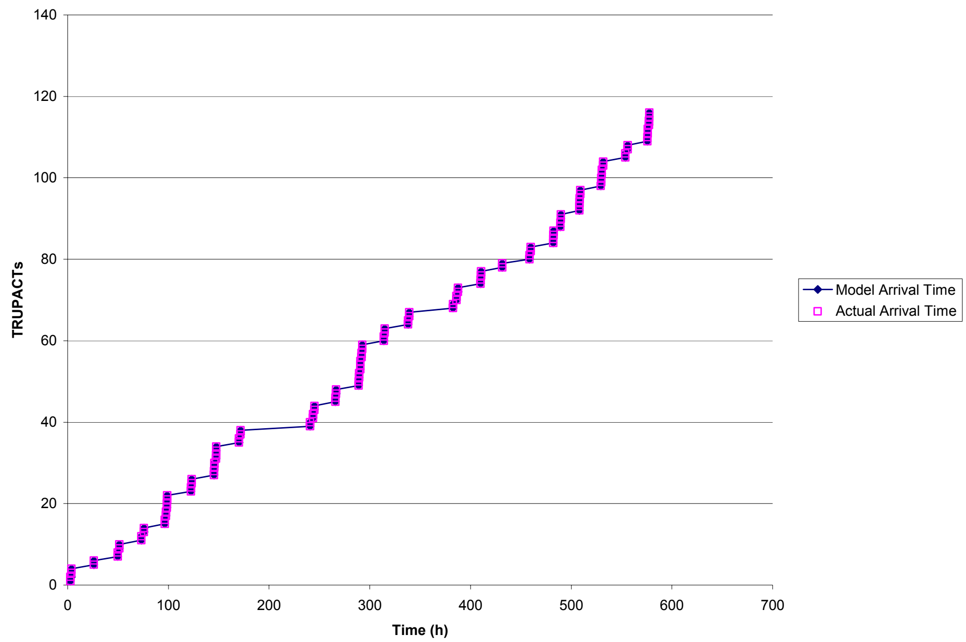

Figure 17: Comparison of TRUPACT Arrival Times for Actual WIPP Data from February 2002 to Simulation Model Arrival Time (Time = 0 Represents 2/1/2002)

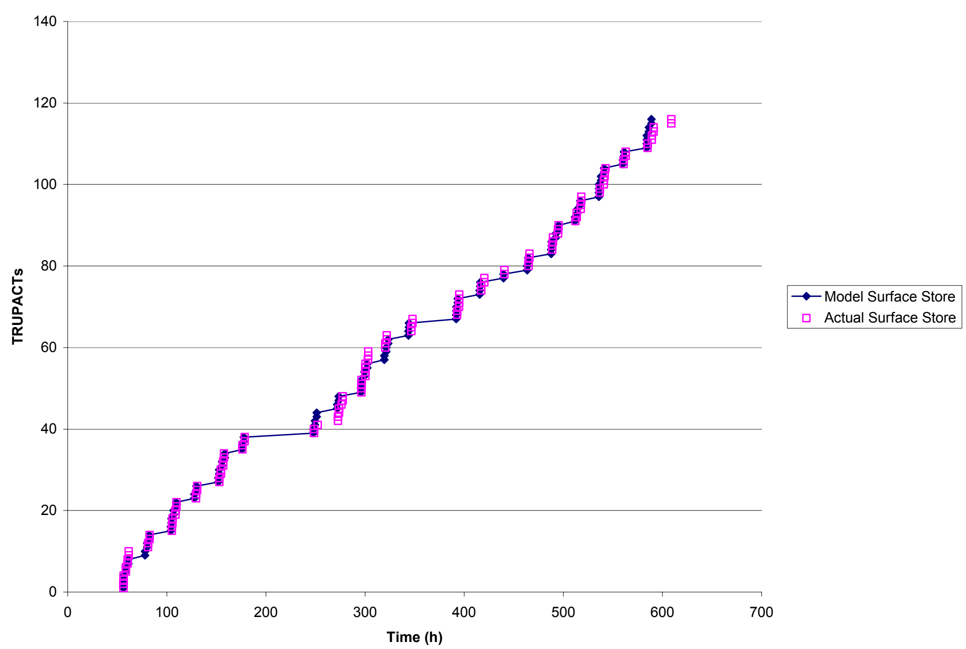

Figure 18: Comparison of TRUPACT Entering Times into Surface Storage for Actual WIPP Data from February 2002 to Simulation Model Arrival Time (Time = 0 Represents 2/1/2002)

Figure 19 shows model emplacement time as compared to actual emplacement time. It is noticeable that the model times and actual times do not match as closely as the previous two figures. This is due to the human logic involved in deciding to download. The model begins the downloading with a fixed logic rule based upon a set number of facility pallets residing in the Surface Storage area. However, in the actual process, the decision is not based upon such concrete, predetermined criteria but human judgment. Although more modeling effort could be spent on evaluating how this decision is made each day by the operating personnel, it was determined that even if it were possible to create an accurate model of the downloading decision, it would be unlikely to contribute much to the overall model of the system. In all likelihood the decision to download is often made in an ad hoc fashion and is influenced by many intangible factors. When higher throughput rates are actually seen at WIPP, the downloading decision will be made on a more concrete set of criteria.

As indicated the model runs on a fixed code to determine when to download. In order to simulate a scenario that will closely mimic the actual downloading decision, without incorporating the complex logic, several cases were examined batching different amounts of Facility Pallets in the Surface Storage area before releasing each to be downloaded. Table 1 shows the errors from each of the different batch scenarios. The linear fit of the "Batch 4" emplacement data had the smallest error when compared against the actual data. Therefore it was selected to run all upcoming validation runs.

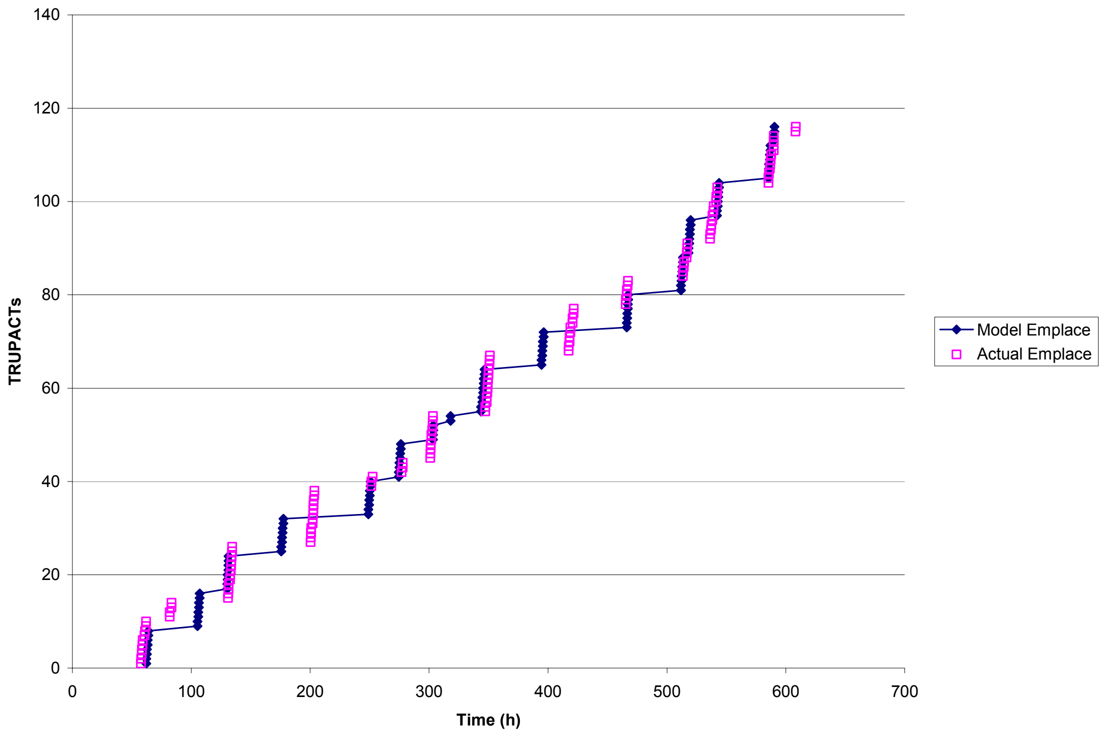

Figure 19: Comparison of TRUPACT Emplacement Times for Actual WIPP Data from February 2002 to Simulation Model Arrival Time (Time = 0 Represents 2/1/2002)

Table 1: Results of Linear Regression Fits of the Actual Emplacement Data and the Modeled Emplacement Time for Various Downloading Batch Sizes

Batch	1	2	3	4	5	Var
Slope Error	-0.73%	0.26%	-0.16%	0.21%	1.70%	-2.41%
Intercept Error	36.50%	12.96%	7.31%	5.98%	66.57%	-5.09%

3.2 Validation Results with February and March 2002 Historical Data

After calibration with data from the February historical data, the model was catalyzed with 2 months of historical arrival data from February and March. The waste handling data for the month of March is not as comprehensive as February's, but comparisons were possible at three different points: arrival, dock processes, and hoist loading. These additional results from March were used to further validate the model.

As in the February results, the arrival times match exactly. At dock processing, however, discrepancies do appear and can be seen in Figure 20. These discrepancies are likely due to some of the same reasoning in the February results. Human decision can affect when some items are moved, but it appears that in general the model suggests that the dock processes begin slightly before the actual data. This is likely due to the fact that no inefficiencies have yet been incorporated into the model. Therefore all equipment is assumed to work all the time, and all personnel are available each shift.

Finally, from the February and March 2002 results, there is a comparison in the time needed to reach the downloading process. As in the February results for emplacement, the individual times for each TRUPACT to reach the hoist are not near exact, but as can be seen by the linear data fit, the rate at which TRUPACTs reach the hoist is off by only 1.2%. Also, as in the February validation results, the discrepancies are introduced due to the human decision making process. These results can be seen in Figure 21.

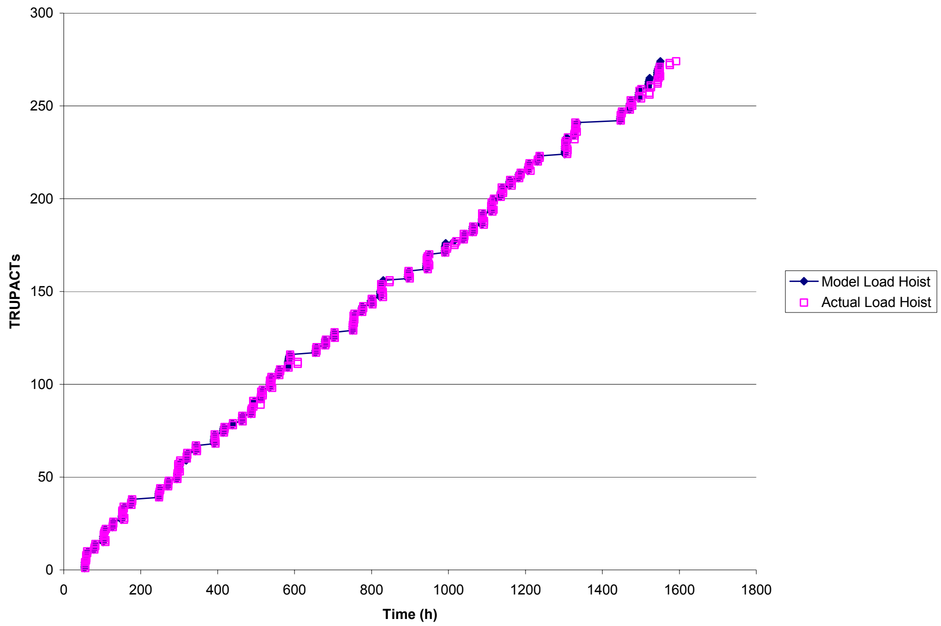

Figure 20: February and March 2002 Time to Reach the Docks Validation Results (Time = 0 Represents 2/1/2002)

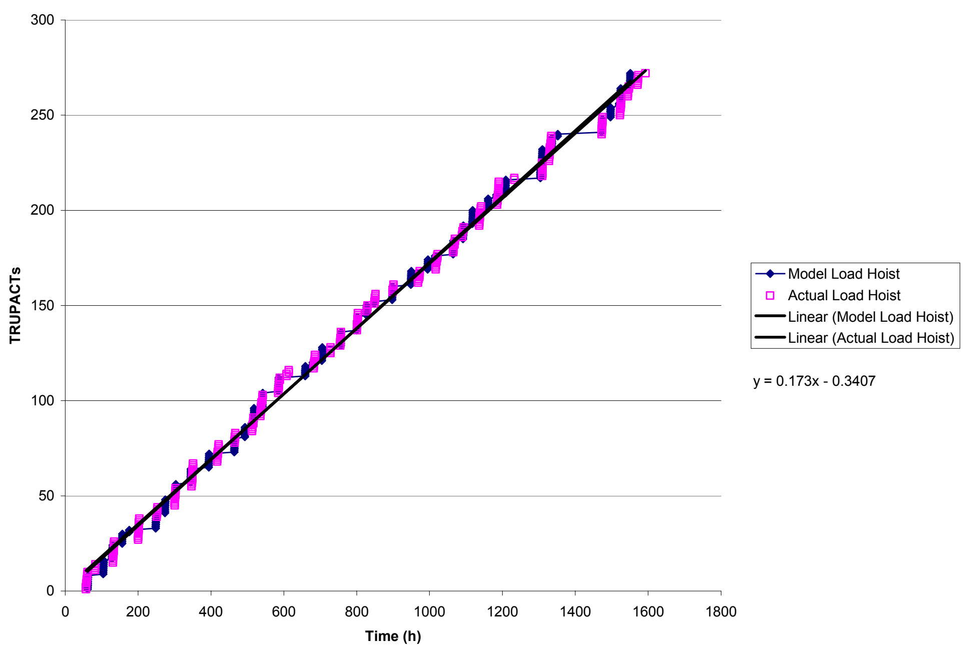

Figure 21: February and March 2002 Hoist Loading Time Validation Results (Time = 0 Represents 2/1/2002)

3.3 Shipments Increased to 110 TRUPACTs per Week with One Shift

The WIPP acceleration plan calls for a future target of approximately 110 TRUAPCT-II's per week to be emplaced [9]. In order to process this desired goal, several resource pools were increased. The following pools were varied: 13 ton fork truck, RCT, WHT-DOCK, and WHT-FYE.

Results indicated that all varied resource pools will need to be increased in order to process the higher rate of TRUPACTs. A total of three 13 ton fork trucks, seven RCTs, ten WHT-DOCKs, and six WHT-FYEs successfully completed the task. These numbers are reasonable because at least eight WHT-DOCK are needed to man each of the TRUPACTs in each dock position accompanied by four RCTs. Two WHT-FYE's are required with the movement of each payload or TRUPACT with the regulation requirement of one RCT per fork truck operation. If the above ground movement was generalized to three categories, unloading, movement inside the building, and loading operations, it is understandable why three fork trucks would be required.

This scenario, however, is sensitive to some inputs such as the day that shipments arrive, the number of people available, and the equipment available. All results are calculated over a two month period. In order for 110 TRUPACTS to be processed in a week's time, at least 15 TRUPACTs must be delivered every day plus five other TRUPACTs to be spread out through the week. If these TRUPACTs are delivered around Wednesday, specifically +2 on Tuesday and +3 on Wednesday, the scenario is successful. However, if

the +2 shipment is on any day other than Tuesday, the scenario fails. As shown in the comparison of Figure 22. The figure also shows the two sets of data breaking away at time equal to 413 hours into the simulation. This is because Wednesdays receive 18 TRUAPCTs and if the system is slowed down it would most likely be noticeable on the heavy shipment days. This congestion of the system also occurs if the +5 shipment occurs all on Wednesday.

The system is most sensitive to change is the Fork Truck resource pool. If the number of fork trucks available is reduced from 3 to 2, the total number of TRUPACTS emplaced is 44% less. The second most sensitive resource in this scenario is the WHT-FYE pool. If this pool is reduced by only 1 FYE, the total number of TRUPACTs emplaced is reduced by 40%.

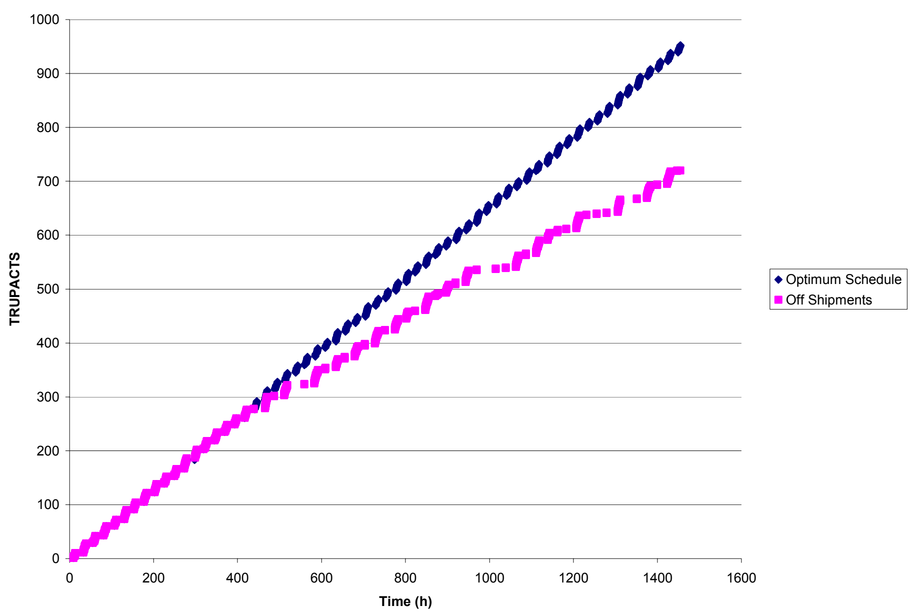

Figure 22: Comparison of the Optimum and Off Shipment Schedules when Emplacing 110 TRUPACTs per Week

3.4 Shipments Increased to 110 TRUPACTs per Week with Two Shifts

In this scenario, 18 TRUPACTs are delivered each day in order to keep the numbers even during downloading and assuming that each trailer has three TRUPACTs. This schedule results in 126 TRUPACTs delivered each week. The goal is to have the first shift download only enough TRUPACTs each day in order to clear space in the Waste Handling Building. The first shift then spends its remaining time unloading payloads unloaded and moving them inside the Waste Handling Building. The second shift spends its efforts emplacing the 10 payloads left in the Waste Handling Building. This requires that the first shift move only 8 payloads to emplacement.

The first shift is comprised of four RCTs, eight WHT-DOCKs, and six WHT-FYEs. This arrangement provides one RCT and two WHT-DOCKs for each dock position. Three couples of FYEs will provide mobility for the waste above and below ground. One RCT will constantly be available to monitor waste movement above and below ground with occasional support by RCTs finishing up dock work.

The second shift is comprised of two RCTs and four WHT-FYEs. This arrangement provides two teams of waste movers. The second shift will move waste from beside the docks and surface storage to the hoist and from the hoist to emplacement. This shift will also be available to load empty TRUPACTs onto trailers. The second shift begins 4:00 PM, the end of the first shift, and the last emplacement occurs before 7:00 PM.

As in the previous scenario, this solution also has some sensitive inputs. These input sensitivities include the number of people available, shipment schedule and the availability of equipment. All results were calculated over the course of a two month period. The loss of one RCT on the first shift results in 44% less TRUPACTs being emplaced. The loss of one WHT-DOCK (effectively two since the resources are called in groups of two) results in the loss of over 50% of the TRUPACT emplacement capacity. The loss of one first shift FYE results in 39% less emplacement.

One the second shift, the result of loosing one RCT or two WHT-FYEs is a 35% reduction in emplacement. These numbers should be equal since one RCT and two FYEs act as a group in waste movement activities.

This scenario has obvious advantages to the one shift scenario. Each day is assumed to receive more than the required amount to emplace 110 TRUPACTs each week. It is therefore reasonable that this configuration of shifts and resources could also handle receiving lesser amounts of waste on some days. This leaves some redundancy in resources on days when receiving less waste. Because this scenario is capable of handling more than the required 110 TRUPACTs and has some redundancy built in, it does appear to be a better solution than the one shift scenario.

CONCLUSIONS AND FUTURE WORK

As demonstrated by the verification and validation steps, this discrete event model of the Waste Isolation Pilot Plant sufficiently simulates the CH waste handling process for answering questions about increasing throughput capabilities.

The model demonstrates its usefulness by evaluating "what-if" scenarios. The data it generates can be used to evaluate whether or not system changes will result in increasing the rate at which CH waste is processed and to what approximate degree. This is particularly valuable because the model can help examine the performance of a system change for a fraction of the cost to modify and evaluate the physical system.

This model is meant to evaluate means to answer large scale questions as implied in the verification and validation steps. Inside these steps the actual day that waste is emplaced may not be accurate, but the rate of waste emplacement is. Therefore the model should be used to examine effects over periods of weeks or months as opposed to determining whether or not a particular TRUPACT of waste will be emplaced on a certain day.

The model accomplished the desired goals. Each of the desired "what-if" scenarios was evaluated and potential bottlenecks were observed. Results indicate that the two shift scenario would be preferable to the one shift scenario because it is able to handle more waste while requiring less people. Both shifts are highly sensitive to loss of personnel, equipment, and changes in scheduling.

In the future, several possibilities exist for the WIPP CH waste model. These include integration with a remote handled (RH) waste process model and the existing transportation model, preparation for online uses, and periodic re-calibration with current production data.

The RH waste process will share some of the same resources as the CH waste process and by integrating the two models the effects of sharing these resources can be evaluated. Integration with existing transportation model will offer insights into the complex relationship between shipping and processing.

Sandia would also like to have a online model that will allow various users to evaluate a limited group of scenarios from the internet with little or no modeling experience. This endeavor will expose a greater number of to the area of modeling and the insight it provides.

Finally, the model can be periodically recalibrated with current processing times to account for personnel learning and procedure modifications.

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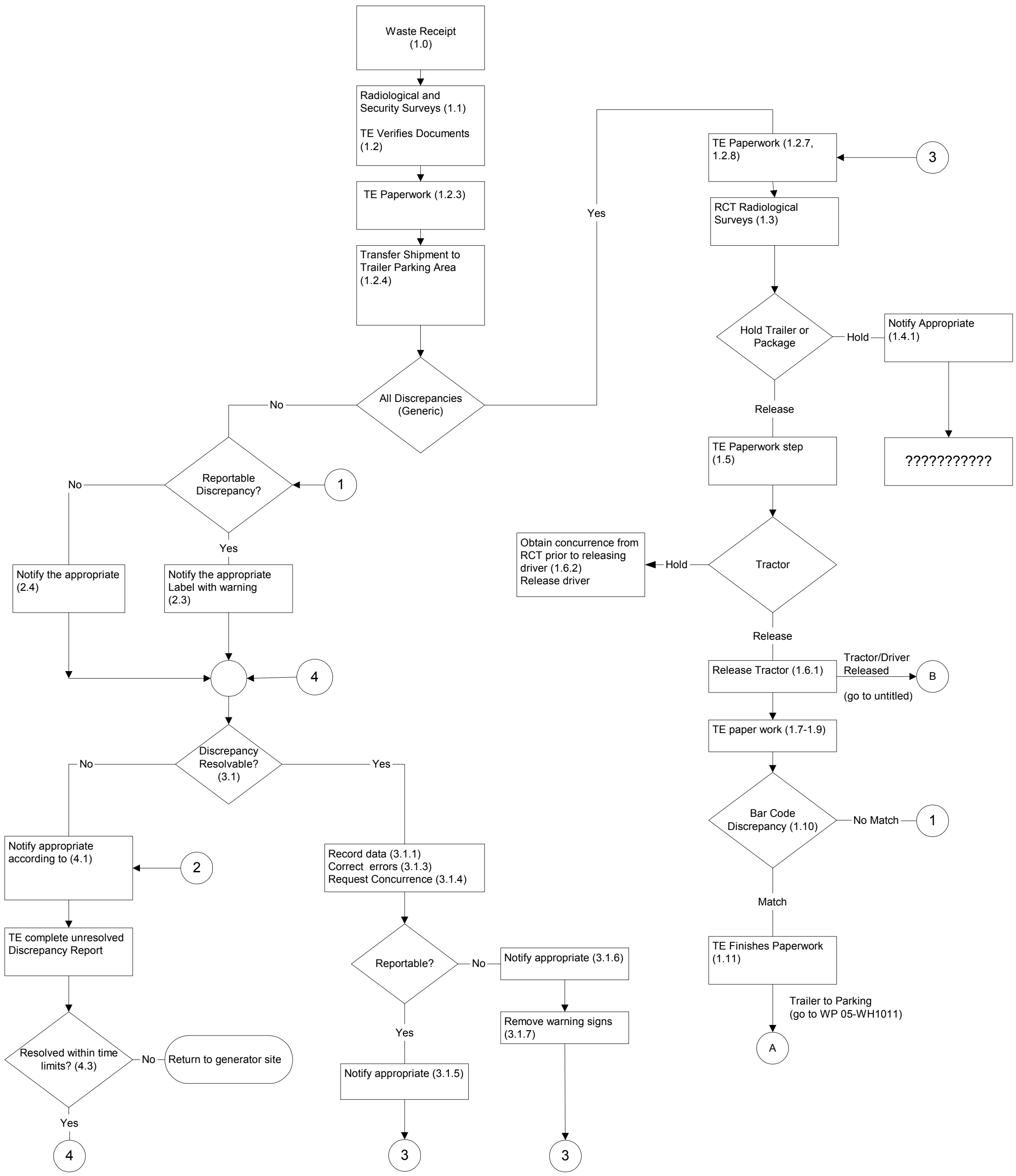
APPENDIX

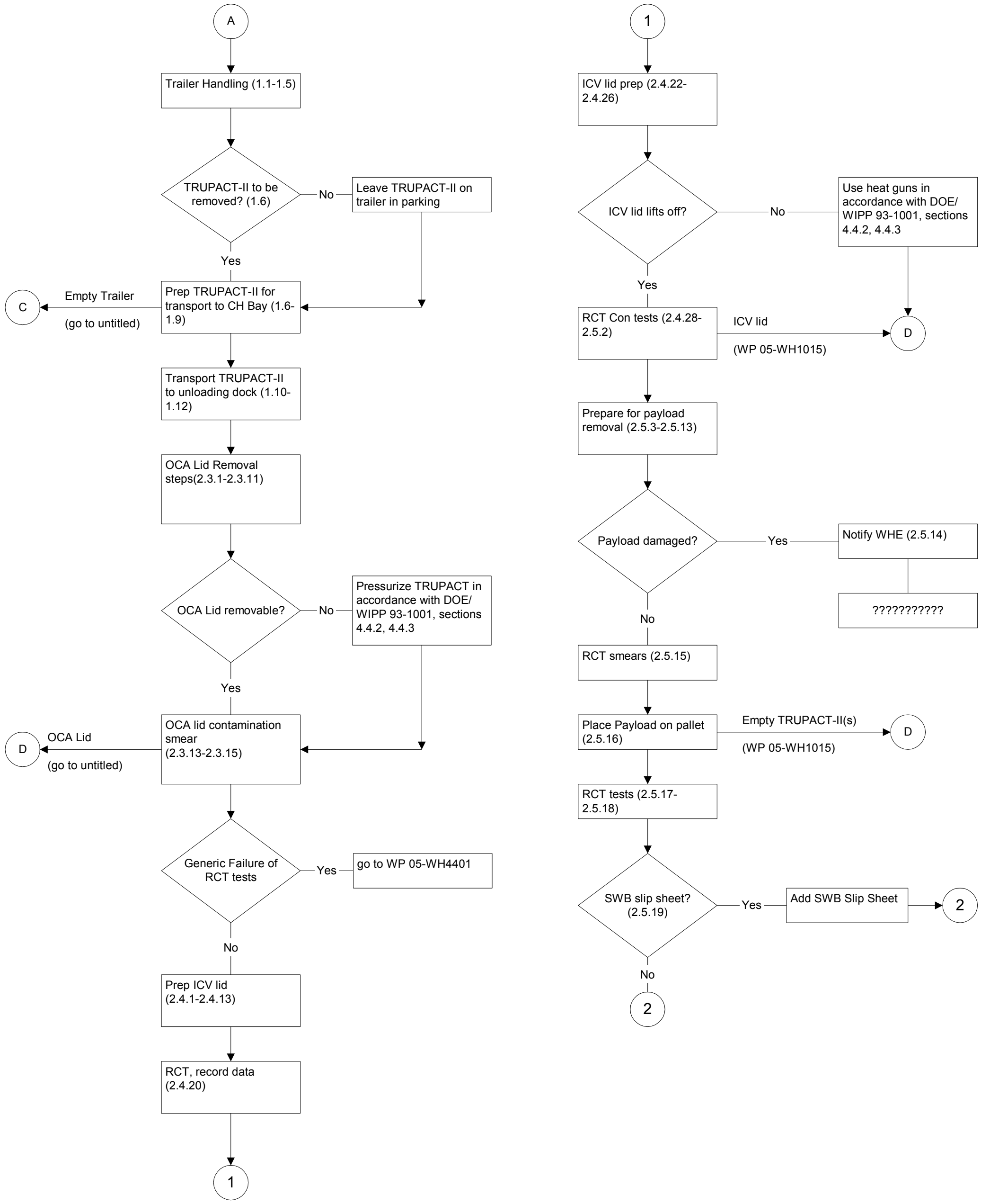
WP 08-NT3020 TRU Waste Receipt



Letters indicate an external Procedure Number connector

Numbers indicate an internal Procedure Number connector

WP 05-WH1011 CH Waste Processing



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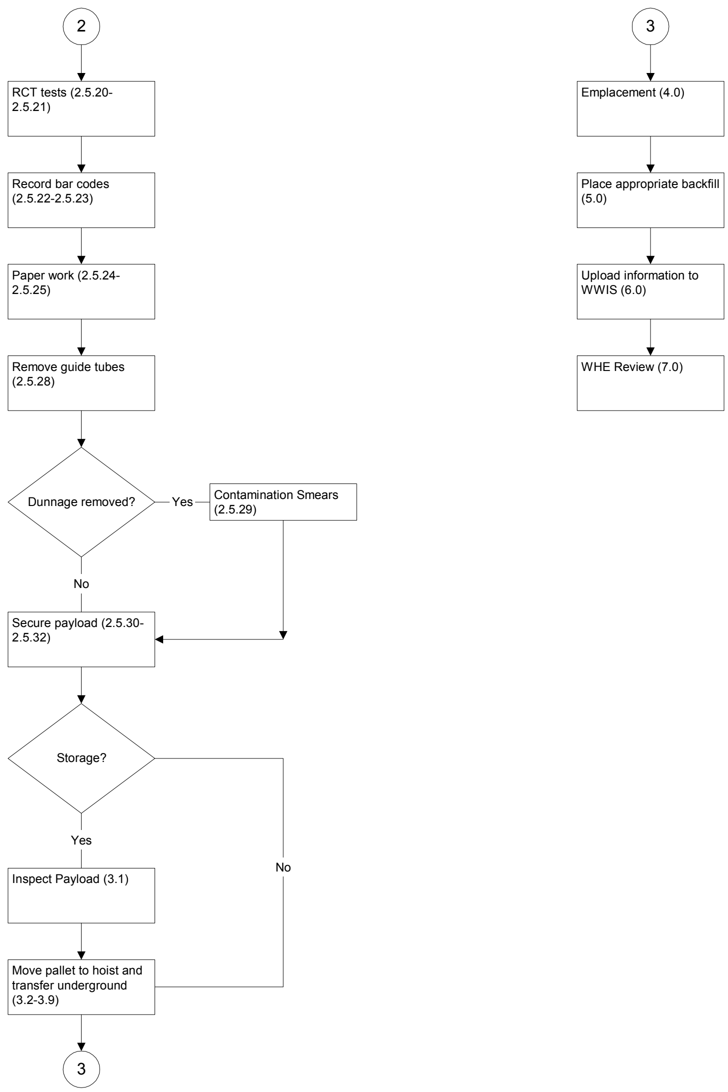

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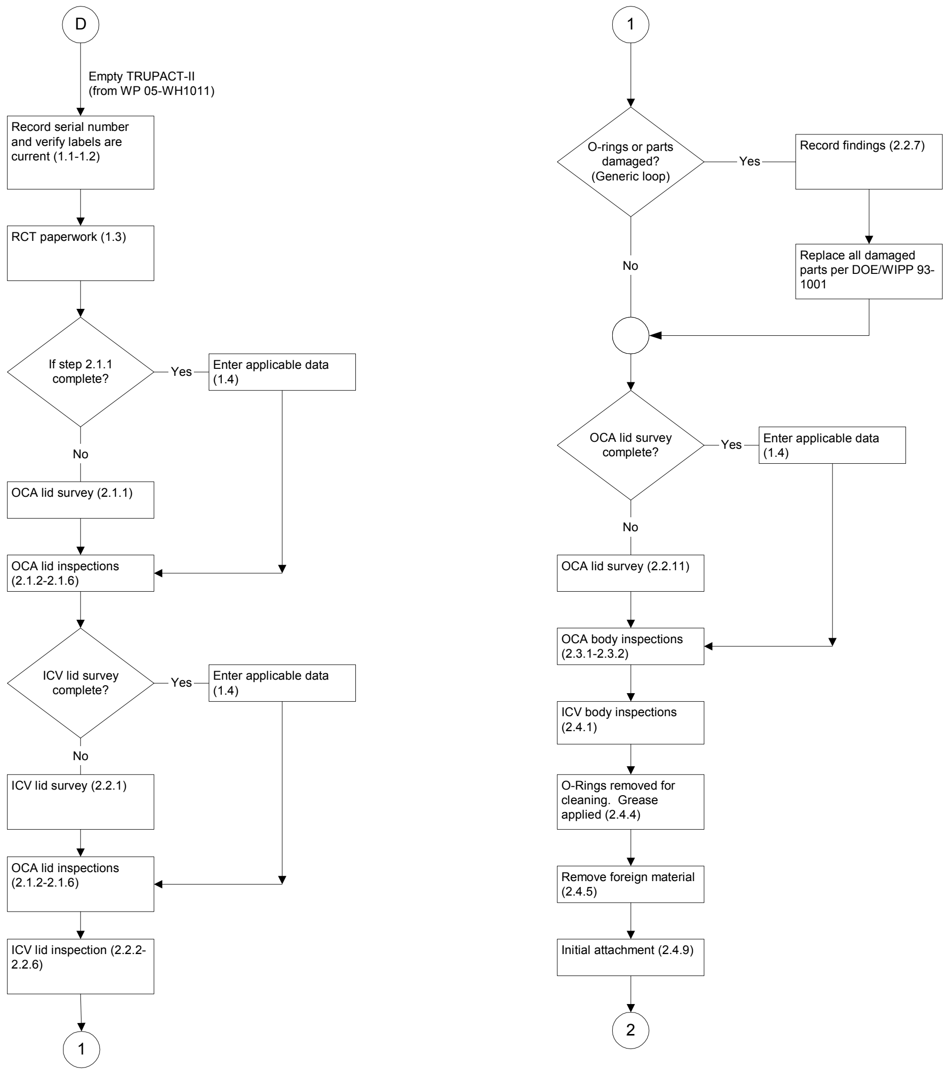
WP 05-WH1015 Preparation of an Empty TRUPACT-II for Shipment



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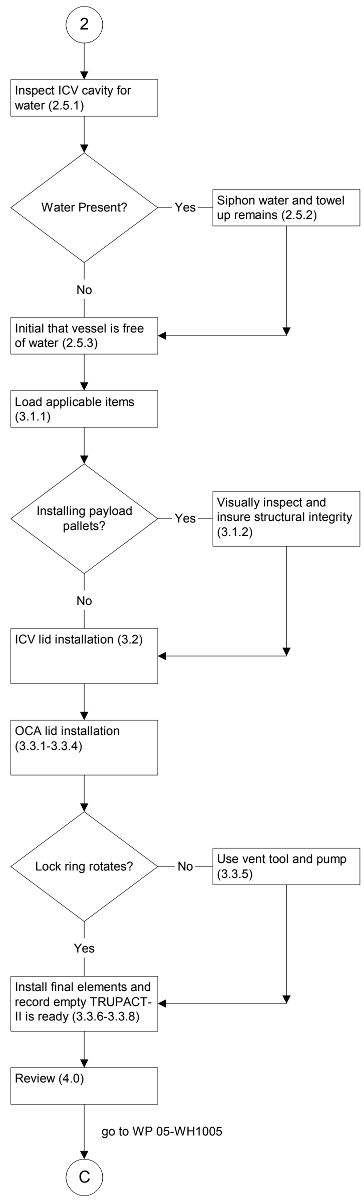
WP 05-WH1015 Preparation of an Empty TRUPACT-II for Shipment



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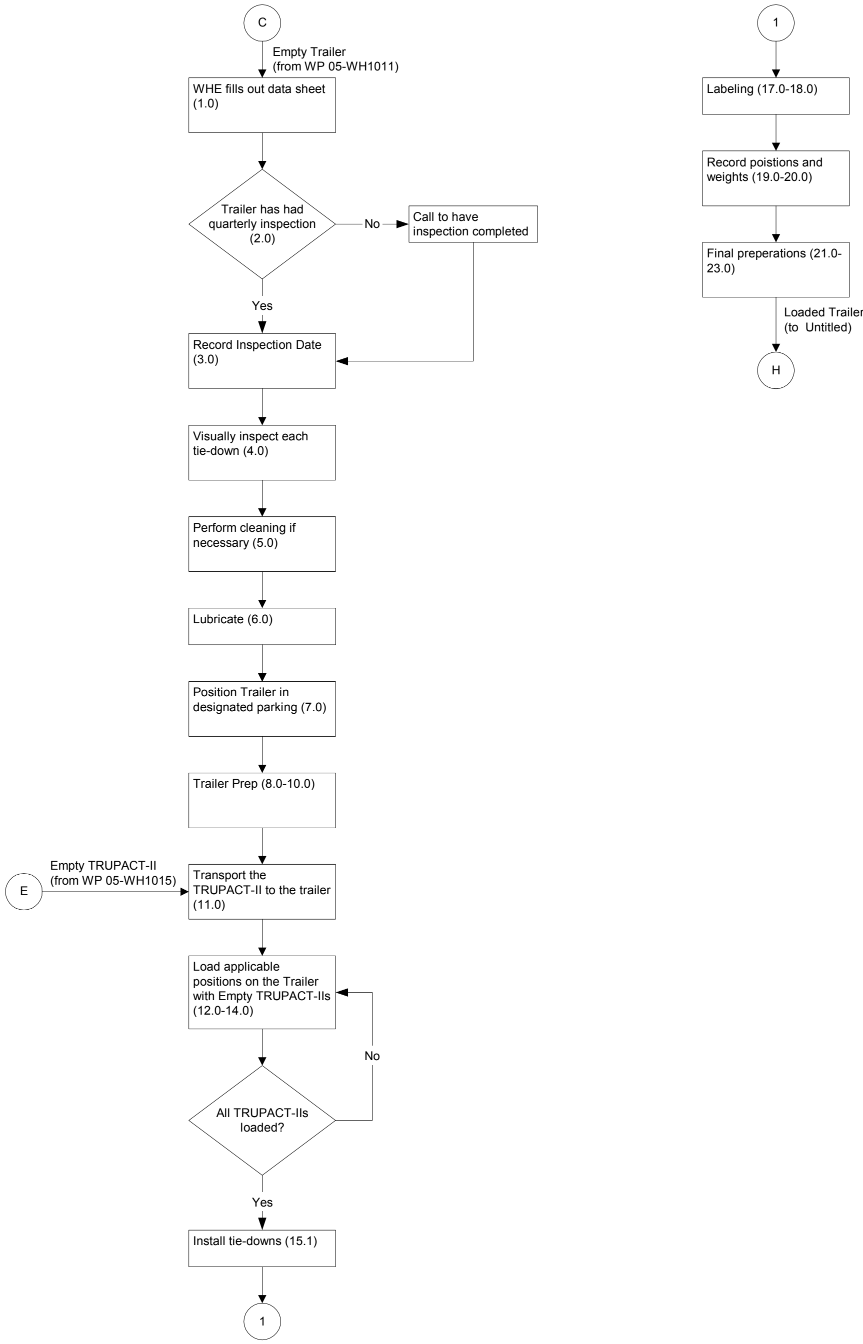
WP 05-WH1005 Loading TRUPACT-II Trailer



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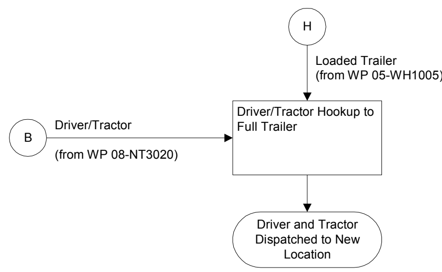
WP 08-NT3030


H
Loaded Trailer
(from WP 05-WH1005)
B
Driver/Tractor
(from WP 08-NT3020)
Driver/Tractor Hookup to Full Trailer
Driver and Tractor Dispatched to New Location

Assumptions for Waste Isolation Pilot Plant Waste Handling Model February 2002

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The University of Tennessee

Carla Mewhinney, Sue Downes
Sandia National Laboratories

Scope

General

The scope of this modeling effort is to develop a discrete event simulation of waste handling operations at the Waste Isolation Pilot Plant (WIPP). This model should include all aboveground and belowground operations in sufficient detail to capture the essential elements of the movement of waste through the pilot plant. Essential elements include modeling of all steps in the process, all of the times required to complete the steps, and critical resources such as personnel and equipment.

Boundaries

The model is bounded at the "borders" of WIPP. Waste materials "enter" the model at the gate of the WIPP. Waste remains in the model as items stored underground. Empty waste containers leave the model at the gate of the WIPP.

Limitations

The model is limited to operations at WIPP. It does not model the movement of waste to WIPP. It can model shipment arrival patterns at WIPP.

Assumptions

Note: If no justification is listed, then either the justification is a physical one (e.g. one crane per dock; 6-ton crane) or it is obvious from the context of the assumption (e.g. no limit on empty TRUPACT-IIs in the parking lot).

Definitions

- CH Contact Handled Waste
- FYE Floor Yard Emplacement
- ICV Inner Containment Vessel
- OCA Outer Containment Assembly
- RCT Radiation Control Technician
- RH Remote Handled Waste
- TE Transportation Engineer
- WIPP Waste Isolation Pilot Plant
- WHE Waste Handling Engineer
- WHT Waste Handling Technician

Units

- Truck = 2 TRUPACTS
- TRUPACT = 14 Drums
- TRUPACT Pallet = TRUPACT = 2 X (7 Pack of Drums) = 14 Drums
- TRUPACT Pallet = Payload
- In general, the word pallet refers to a Facility Pallet (2 TRUPACTs)

General Assumptions

- One cannot mix CH and RH waste processing within the CH bay of the waste handling building. JUSTIFICATION: Regulation
- Limited to 252 drums of waste in waste handling, based upon a permitted storage capacity of:
    - 4 loaded TRUPACT-IIs in the docks (56 drums) and
    - 7 loaded facility pallets (196 drums)
- JUSTIFICATION: Hazardous Waste Permit
- Limited to 12 Trucks (24 Loaded TRUPACTS in the parking lot. JUSTIFICATION: Regulation

Equipment

- Crane
    - 1 per dock
    - 6 ton capacity
    - Time to return to stowed position not currently modeled
- Fork Trucks
    - 6-ton truck
        - 1 in WIPP
        - 8 hour charge time
        - 90% availability. JUSTIFICATION: Discussion with WIPP staff
        - Only truck used for movement of dunnage. This forklift is not currently included in the model. JUSTIFICATION: Procedure
    - 13-ton trucks
        - 2 in WIPP
        - 4 hour charge time
        - 90% availability. JUSTIFICATION: Discussion with WIPP staff
- Hoist
    - 1 waste hoist at WIPP
    - Capacity = 1 facility pallet (loaded or unloaded)
    - 10 minutes per trip from stowed position
    - Waste and personnel may not be transported by the hoist at the same time
    - 5 hours maintenance/shaft inspection per week
    - Normally operates from 7:30 to 15:45 for waste handling activities (other times are used for mantrips)
    - Tours, planned PMs, and other materiel handling also impact hoisting operation for about 1 hour/day
- Pallets

        - Facility (Rectangular Shaped), Capacity 2 Payloads. Denoted as Facility Pallets or Pallets.
            - 9 are available
            - No waste may be stored on a facility pallet in the underground
            - Only 1 Facility pallet on the hoist at any time
        - TRUPACT (Round Shaped), Capacity 2 X 7 Drums. Denoted as TRUPACT Pallets.
            - Returned to surface and replaced in clean, empty TRUPACTs
            - 30 are available
    - TRUPACTS
        - 51 in DOE
        - Generally 25% out of service at any time
    - Underground Equipment
        - Transporter
            - 2 available
            - When 1 crew is available, only 1 transporter is used. When 2 crews are available, 2 transporters are used

Locations

- Security Gate
    - Does not operate on a shift. JUSTIFICATION: Procedure
    - Arrival schedule can either be a typical average schedule or the actual arrival schedule
    - Only 1 truck is allowed in the security gate at a time
- Inbound Parking Lot
    - 12 loaded TRUPACT limit
    - No limit on empty TRUPACTs JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
- Outbound Parking Lot
    - No limit on empty TRUPACTs
    - Departure schedule is arbitrary.
- Docks
    - East and West docks
    - 2 unloading positions per dock; Denoted Position 1 & 2
    - 4 loaded TRUPACTs allowed in the docks at a time. Limited to 1 TRUPACT per Position JUSTIFICATION: Regulation
    - Each dock has 1 crane which is shared by both positions
    - Requires 2 WHT-Dock and 1 RCT for all activities.
    - When one crew is available only 3 docks are used. When both crews are available, all 4 docks are used.
    - Open TRUPACTs may be left overnight in the docks with waste in them – no waste may be left on facility pallets overnight sitting at a dock
    - Work may not start at docks until facility is placed in waste handling mode (usually about 6:30 am)
    - JUSTIFICATION: Regulation and Procedure
- Surface Storage Area

- Limited to 7 loaded facility pallets.
- Normally 5 loaded pallets are accumulated before downloading into the underground
- JUSTIFICATION: Regulation

Personnel

- RCT 4 on A shift and 4 on B shift, 1 on call 24/7
- TE on call 24/7
- WHT-Dock 8 on A shift and 8 on B shift
- WHT-FYE 3 on A shift and 3 on B shift
- Shifts
  - Currently modeling only one type of labor shifts.
  - Alternating A and B shifts of 5 10-hour days one week and 3 10-hour days the following week.
  - Crew A and B work 6 am to 4 pm. Both crews are available on Wednesdays.
  - 2 Week Schedule:

	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
A		On	On	On			On	On	On	On	On			
B	On			On	On	On					On	On	On	On

Operations at the Locations

- Security Gate
  - Security Survey
    - Requires 1 RCT, 1 TE (available 24/7)
    - 10 minutes
    - Done whenever a shipment arrives
    - JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
- Inbound Parking Lot
  - Radiation Survey
    - Requires 1 RCT, 1 TE (available 24/7)
    - 90 minutes
    - Done whenever a shipment arrives
    - JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
  - Unload and transport to dock
    - Requires 2 of either WHT-FYE or WHT-Dock, 1 RCT
    - Requires 1 13-ton Fork Truck
    - 20 minutes
    - Uses current 10 hour/day shift schedule
    - JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff

- Outbound Parking Lot
  - Transportation to Truck
    - Requires 2 of either WHT-FYE or WHT-Dock
    - Requires 1 13-ton Fork Truck
    - 10 minutes
    - JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
  - Load onto Truck
    - Requires 2 of either WHT-FYE or WHT-Dock
    - Requires 1 13-ton Fork Truck
    - 40 minutes
    - JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
  - Truck Leave Gate
    - Requires 1 Gate
    - 10 minutes
    - JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff

- WIPP Waste Handling Building (Building 411) Airlock
  - Move TRUPACTs from Truck to Dock through Air Lock
    - 1 TRUPACT at a time. JUSTIFICATION: Regulation
    - 5 min/TRUPACT. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff

- Docks
  - OCA Lid Removal Position 1
    - Requires 1 Crane
    - 11.5 minutes to remove. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - 5 minutes to smear. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - 0.1% failure rate on removal. JUSTIFICATION: Discussion with WIPP Staff
    - 0.1% failure rate on smear. JUSTIFICATION: Discussion with WIPP Staff
  - OCA Lid Removal Position 2
    - Requires 1 Crane
    - 8 minutes to remove. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - 5 minutes to smear. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - 0.1% failure rate on removal. JUSTIFICATION: Discussion with WIPP Staff
    - 0.1% failure rate on smear. JUSTIFICATION: Discussion with WIPP Staff

- ICV Lid Removal Positions 1 and 2
    - Requires 1 Crane
    - 11 minutes to remove. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - 20 minutes to perform hood test. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - 5 minutes to smear. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - 0.1% failure rate on removal. JUSTIFICATION: Discussion with WIPP Staff
    - 0.1% failure rate on hood test. JUSTIFICATION: Discussion with WIPP Staff
    - 0.1% failure rate on smear. JUSTIFICATION: Discussion with WIPP Staff
- Payload Removal Position 1
    - Requires 1 Crane
    - 10 minutes to remove. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
- Payload Removal Position 2
    - Requires 1 Crane
    - 11.5 minutes to remove. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
- TRU Assembly
    - Requires 1 Crane, 2 TRUPACT Pallets, 1 Facility Pallet
    - 30 minutes to assemble. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff

- Surface Storage Area
    - Move from dock into storage
        - Requires 2 of either WHT-FYE or WHT-Dock. JUSTIFICATION: Regulation
        - Requires 1 13-ton fork truck.
        - 5 minutes. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - Move from storage to hoist
        - Requires 2 of either WHT-FYE or WHT-Dock. JUSTIFICATION: Regulation
        - Secure Payloads Prior to Moving Underground
        - Requires 1 13-ton fork truck.
        - 10 minutes. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff
    - Downloading
        - Requires hoist
        - 20 minutes. JUSTIFICATION: Direct or Video Measurement and/or Discussion with WIPP Staff

- Underground
    - Requires 1 WHE, 1 RCT, and 2 WHT-FYE for all operations.
      JUSTIFICATION: Regulation and procedure.
    - Occupies the drift.
    - The entire process (full pallet in storage to empty pallet in storage) takes 45-50 minutes

VITA

Benjamin Thomas Burnette was born in Knoxville, TN on November 6, 1977. He was raised by his parents Bob and Joy Burnette in Strawberry Plains, TN were he attended public schools. In 1996 he graduated form Jefferson County High School and began his studies at the University of Tennessee Knoxville (UTK) in the fall of that same year. In May of 2001, He graduated UTK with a Bachelor of Science in Mechanical Engineering.