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THE HANFORD WASTE FEED DELIVERY OPERATIONAL RESEARCH MODEL

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ABSTRACT

The Hanford cleanup mission is to vitrify 56 million gallons of nuclear waste, currently stored in 177 underground tanks, at the Waste Treatment and Immobilization Plant (WTP). The WTP operations begin in 2019. Waste transfers from the Tank Farms to the WTP utilize an intricate and complicated Waste Feed Delivery system. This equipment is used infrequently, hard to access, and difficult to maintain. Over the next nine years it must be prepared to safely and reliably transfer waste to the WTP. The Hanford Waste Feed Delivery Operational Research (WFDOR) model simulates actual Hanford operations and uses historical reliability data from Hanford, the Savannah River Site, and appropriate generic databases. The results of the study will enable key decision makers to focus on the necessary upgrades to the Hanford WFD system. This paper will discuss the modeling approach and methodology used to develop the WFD OR model.

1 INTRODUCTION

The U.S. Department of Energy, Office of River Protection manages the River Protection Project. The River Protection Project mission is to retrieve and treat the Hanford Site's tank waste and close the tank farms to protect the Columbia River. The tank contents include waste from World War II and Cold War era nuclear weapons production, and account for 60 percent by volume of the nation's high level radioactive waste. These aging and leak prone single-shell tanks are just a few miles from the Columbia River and within a 50-mile radius of more than 200,000 residents.

Washington River Protection Solutions is the U.S. Department of Energy, Office of River Protection's prime contractor responsible for safely retrieving approximately 56 million gallons of highly radioactive and hazardous waste stored in 177 underground tanks. The waste is stored in 149 older single-shell tanks and 28 newer double-shell tanks that are grouped in 18 farms on the 560-square mile Hanford site. The Office of River Protection cleanup mission is to retrieve waste from single-shell tanks, pre-treat and stage the waste in the double-shell tanks, and transport the waste to the Waste Treatment and Immobilization Plant (WTP). At the WTP it will be vitrified for safe long term storage.

Waste transfers to the WTP will utilize a complex network of equipment that comprises the tank farms. Besides the 149 SSTs and 28 double-shell tanks, this network is composed of an evaporator, pumps, valves, leak detectors and other instruments, and thousands of feet of underground piping. This equipment is used infrequently, hard to access, and extremely difficult to maintain. Over the next several years the tank farms must be prepared to safely and reliably transfer waste to the WTP. The tank farms mission is expected to be complete within the next 40 years. Successful completion of the Office of River Protection cleanup mission is dependent on identifying key risk areas and the necessary equipment upgrades that are required to support WTP operations.

This paper discusses ways that Energy*Solutions* is using OR modeling as a tool to predict the performance of this process before actual waste transfers commence. Modeling is providing an invaluable insight into predicted operations of the tank farms, taking into account the resources, equipment, complex interactions, constraints and random variability that will likely be experienced during actual operations. This paper also discusses ways that modeling can be used as a tool to accurately forecast key performance characteristics associated with the tank farms including Total Operating Efficiency (TOE); mission timescales; overall equipment utilization, identification of key bottlenecks and the necessary upgrades to successfully complete the mission.

2 MODELING APPROACH

Strategic planning at the Hanford Site is a complex and iterative process. The Hanford Tank Waste Operations Simulator (HTWOS), a dynamic flowsheet simulation and mass balance computer model, is used to simulate the current planned River Protection Project mission, evaluate the impacts of changes to the mission, and assist in planning near term facility operations. Development of additional modeling tools, including a Waste Feed Delivery OR Model will help to mitigate operational risks and further improve long term planning confidence.

The Waste Feed Delivery OR Model is currently being developed using the WITNESS™ simulation software, a discrete event simulation tool that is used by thousands of organizations in virtually every industry to achieve process performance excellence. Discrete event simulation works through modeling individual events that occur at given time intervals, taking into account resources, equipment, constraints and interactions. Discrete event models also include the randomness and variability that occurs in real life, and behave like real life processes such as production lines, airport baggage handling systems, etc.

The Waste Feed Delivery OR Model interfaces with HTWOS output via an Excel spreadsheet. HTWOS incorporates a simplified assumption that the WTP will achieve 70% TOE. The Waste Feed Delivery OR model develops a more realistic prediction of operating efficiency by incorporating the reliability, availability, maintainability and inspectability of more than 525 individual tank farm components including mixer pumps, transfer pumps, valves, jumpers, leak detection instruments. The HTWOS system plan outputs and the results from the Reliability Availability Maintainability (RAM) analyses including Mean Time Between Failures, Mean Time To Repair, and other operational losses are inputs into the Waste Feed Delivery OR model. The resulting OR model, when fully developed, will simulate the impacts of the reliability and maintenance of each item of equipment and the impacts of labor availability on mission timescales. It will help identify reliability-related cost and schedule drivers and find ways to mitigate them. This unique approach will ensure improvements are focused, equipment and resources are managed early, operations and maintenance costs are reduced, throughput and performance are improved and mission length is assured.

3 HANFORD TANK FARMS – SYSTEM DESCRIPTION

The Hanford tank farms are comprised of a complex network of inter-dependent waste storage, retrieval, treatment and disposal facilities in varying stages of design, construction, operations and future planning. The major processes include waste storage, retrieval, treatment and disposal.

3.1 Waste Storage

The Hanford tank farms include 177 underground tanks in two basic designs: single-shell tanks and double-shell tanks. There are 149 single-shell tanks, each having a storage capacity between 55,000 and one million gallons. There are 28 double-shell tanks, each having a storage capacity between one and 1.25 million gallons. The double-shell tanks play three critical roles in the tank farms: they receive and store the waste retrieved from the single-shell tanks; they stage waste for subsequent delivery to the WTP; and they support evaporator operations to minimize the total volume of waste that needs to be stored.

All 177 waste storage tanks were built underground and are clustered in 18 groups or "farms" with two to 18 tanks per farm, spread across several square miles. Waste transfers between tanks and related facilities occur via installed double-encased underground transfer lines, or temporary high integrity hose-in-hose above ground transfer lines. The vast majority of tank waste resides in the single-shell and double-shell tanks. However, a small amount of waste is also stored in Inactive Miscellaneous Storage Tanks or other site facilities.

The total Hanford tank waste inventory is approximately 56 million gallons, containing an estimated 177 million curies of radionuclides.

3.2 Waste Retrieval

Retrieval of wastes from the single-shell tanks has already commenced. A variety of waste retrieval techniques have been employed. The method used for retrieval depends on the nature of the waste, tank integrity, tank design and various other factors. The modified sluicing method is performed with double-shell tank supernatant and used to retrieve large quantities of sludge from the single-shell tanks. The modified sluicing with water method is used to dissolve saltcake in the single-shell tanks. Vacuum retrieval relies on a multi degree-of-freedom mast and manipulator arm inserted through the tank's central riser, capable deploying a vacuum wand throughout a large volume envelope within the tank. A mobile retrieval system combines a vacuum retrieval system with an in-tank, tracked, remotely operated vehicle to push or sluice waste toward the vacuum inlet.

3.3 Waste Treatment

The waste retrieved from the single-shell tanks is stored in the double-shell tanks where it is consolidated into feed batches for the WTP. The double-shell tanks will be used to transfer waste directly to the WTP Pretreatment Facility, where the waste is processed into two streams; high-level waste and low activity waste. The high-level waste contains most of the radionuclides and will be vitrified into a glass waste form and poured into stainless steel containers to be stored temporarily on-site, pending a final decision on disposal at an off-site repository. The low activity waste, which contains fewer radionuclides will also be vitrified into a glass waste form in a separate facility and subsequently disposed at a permitted facility on the Hanford Site. WTP is under construction and is expected to begin hot operations in 2019.

4 MODEL DESCRIPTION

The Waste Feed Delivery OR Model has a multitude of input and output parameters associated with it. A snapshot of the same is provided below, followed by a high-level description of the major functionalities/features. Figure 1 shows the overall setup of the model. Note that this paper focuses discussion only on the Waste Feed Delivery side of the operations.

4.1 Inputs

4.1.1 Batch Transfer List

Excel input file was developed based on the HTWOS model results data. The model input file includes batch transfer volumes, volumetric flow rates, transfer routing, precedence constraints and transfer cycle times.

4.1.2 Start Conditions

The model input file also includes the model startup conditions including initial SST and DST start volumes. The maximum required tank volumes have been back calculated based on the starting volumes and transfer volumes from the HTWOS transfer list. This method ensures that the maximum tank volume used in the WFD OR model can support all waste transfers made in the HTWOS transfer list. Tanks will not be overfilled since all of the transfers made in the WFD OR model follow the HTWOS transfer list.

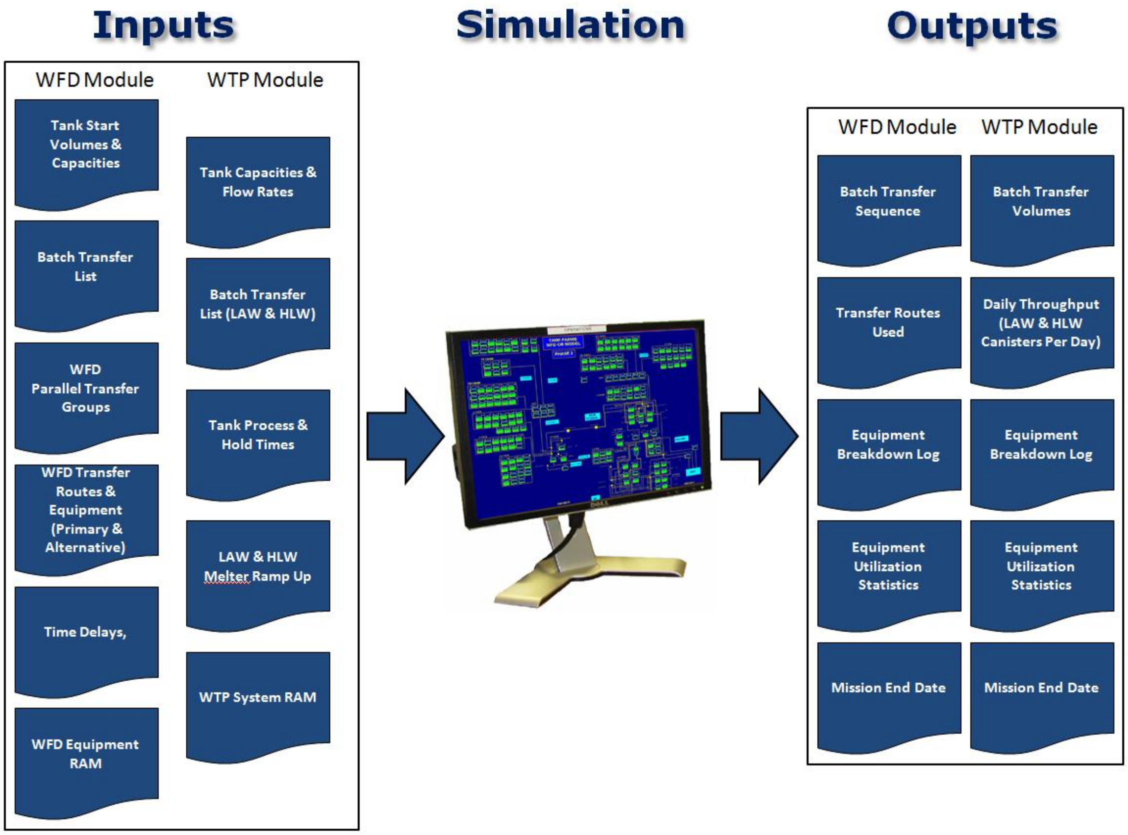

Figure 1: Waste Feed Delivery OR Model Inputs and Outputs

4.1.3 Transfer Dependencies

The WFD OR model will alter the order of transfers in the HTWOS transfer list to a certain extent, if certain conditions can be met. One condition is dependent transfers. Dependent transfers are those that rely on other waste transfers to be complete before the transfer can be made. In other words, a tank cannot be emptied before it is filled and, a tank cannot be filled before it is emptied. Transfer dependencies have been maintained in the WFD OR model such that these events will never occur. Even if transfers in the OR model are made in a slightly different order than transfers in the HTWOS model, each individual transfer will only be made if the transfers leading up to the transfer in question have already been made.

4.1.4 Parallel Transfers

Some of the transfers identified in the transfer list can be performed in parallel. The various tanks within the Tank Farms have been separated into five groups (Groups 1 thru 5) based on their physical location and function. A maximum of two transfers can performed in parallel within each of the five groups and a maximum of 10 transfers can be performed within the Tank Farms. Several constraints have been considered when performing parallel transfers. These constraints are:

- If two transfers within the same group demand the same transfer equipment, only one of the transfers can occur
- Dependent Transfers - Transfers out of one tank that depend on transfers coming into a tank cannot be made until the transfer into a tank has been made
- Transfers will not made out of a tank if any of the tank equipment has failed or the transfer route equipment has failed and there is no alternative transfer route

- Time constraints, e.g. equipment set up times; sampling times; equipment installation schedule and WTP processing rates are all observed while making parallel transfers

4.1.5 Transfer Delays

The WFD OR Model includes the following transfer delay times.

- SST Set Up Times
- DST Route Set Up Times
- Sampling Delays - 242-A Evaporator Campaigns and LAW and HLW feed staging
- WTP processing rates
- Equipment Upgrade and Installation Schedules

4.1.6 Transfer Routes

For every DST to DST transfer, Evaporator campaign, and DST to WTP transfer, detailed transfer route information with the primary route as well as alternate route information (up to 10 alternate routes) is read in from the Excel spreadsheet. The transfer route includes equipment such as transfer lines, jumpers, mixer pumps, transfer pumps, electrical system, ventilation system and leak detectors.

4.1.7 Equipment Reliability, Availability and Maintenance

Waste Feed Delivery system equipment reliability data has been data gathered to the extent possible from previous operating experience at Hanford, the Savannah River Site (SRS), and generic data bases. The reliability data has been included in an Excel spreadsheet that is used as input to the WFD OR model to simulate equipment failures. The equipment reliability data includes the Mean Time Between Failure (MTBFC) based on the calendar time; Mean Time Between Failure (MTBFO) based on operating time; Mean Demands Between Failure (MDBF) based on number of demands, and Mean Time To Restore (MTTR) for each item of system/equipment.

4.2 Model Setup & Features

The WFD model is a collection of elements that are linked together in a unique yet logical way to represent the day-to-day operation of the WFD system. The WFD system has been modeled using both discrete (e.g. machines) and continuous (tanks and pipes) elements. The discrete elements are active and drive the working of the model of the most part. The continuous elements are passive and are driven by the discrete elements. Figure 2 shows the overall setup of the model.

Single-shell tanks, Waste Retrieval Facilities (WRFs) and DSTs have been modeled using a group of discrete and continuous elements. Each SST, WRF and DST has been modeled using a tank, pipes and machine elements (see Figure2). Each tank is used to receive and store liquid and solid waste and receive and store dilution water, process water, 11-molar caustic, etc. from external sources. Pipes are used to transfer liquids, solids, dilution water, etc. from one tank to another or from a tank to an evaporator. Machines are used to activate the movement of liquid, solids, dilution water, etc. through the WFD systems in the model. Delay times associated with each tank (e.g. transfer delays, sampling times, etc.) and in-tank equipment failures (e.g. transfer and mixer pump failures) are simulated.

Each tank group (i.e. tank, pipe, machine) has its own variable arrays that contain specific data relating to each individual SST, WRF or DST. At the start of a simulation run, the model reads in the SST, WRF and DST model input parameters including start volume, capacity, delay times and equipment RAM data (e.g. MTBF, MTTR etc).

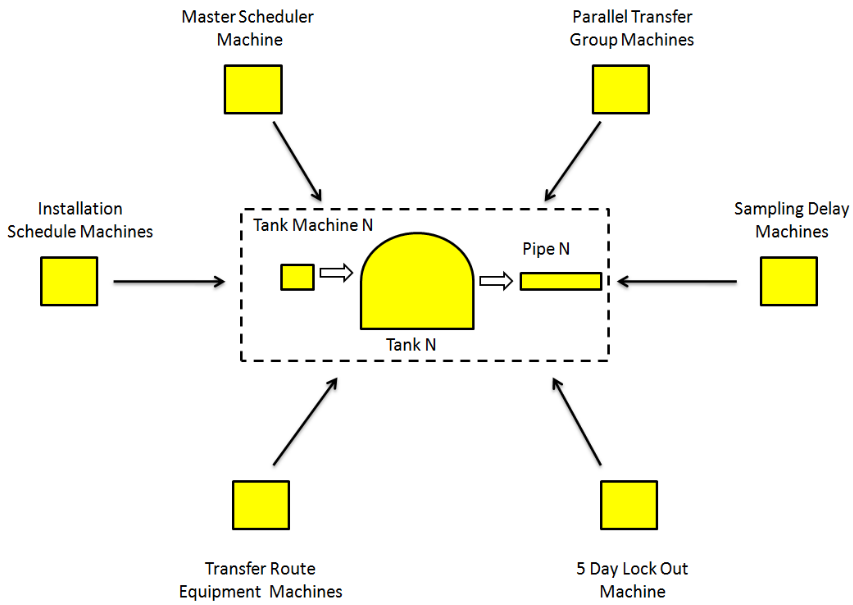

Figure 2: Model Structure

4.2.1 Modeling Batch Transfers

When both the upstream and downstream DSTs are ready for a transfer and there are no other conditions or control logic preventing the transfer of waste, the batch control procedure sends a signal to DST-Control System Machine which sends a signal to the Pipe attached to DST (Source Tank) and activates the pipe using the Repair Function. The pipe then transfers the specified waste volume to the designated SST/WRF/DST (Destination Tank). The DST–Machine is used to activate the transfer of waste from the source tank into the destination tank. The machine cycle time is calculated based on the transfer volume divided by the flow rate specified in the input file. After each batch transfer, variable arrays detailing liquid, solid and dilution volumes and flow rates are updated.

Once the batch transfer is complete, the pipe attached to the source tank is deactivated using the Breakdown Function. At the same time, a signal is sent to the DST Control System to indicate that the transfer is complete and the tank is now ready for the next batch transfer.

4.2.2 Parallel Transfer Selection

The model decision logic flow for parallel transfers is illustrated in Figure 3. At the start of the simulation, the parallel transfer groups are read into the model from the model input file. The parallel transfer group machine will then read in the maximum number of parallel transfers that can occur within each group. The Master Scheduler machine will determine whether a parallel transfer can occur based on the transfer list. If a parallel transfer can occur, then the associated parallel transfer group machine will be activated.

If the transfer can occur but cannot start due to some other constraint, the parallel transfer group machine will be deactivated. The parallel transfer group machine will then check to see if the precedence constraints have been satisfied. If the precedence constraints have not been satisfied and the transfer is dependent upon another transfer before the transfer can be performed (i.e. dependent transfer), the transfer group machine will be deactivated. If the precedence constraints have been satisfied, the parallel transfer group machine will then check to see if the transfer route equipment is available for transfer (i.e. it is not being used by another transfer or the transfer equipment has failed and is being restored or the equipment is being set up). If the equipment is not available for transfer, the parallel transfer group machine will be deactivated. If the equipment is available for transfer, the parallel transfer group machine will check to see if the receiving tank is available for transfer (i.e. it is not being used by another transfer or the tank equipment has failed or the tank is being upgraded). If the tank is not available, the parallel transfer group machine will be deactivated. If the tank equipment is available, the transfer number will be assigned based on the transfer list and the transfer will be activated and the transfer will be performed.

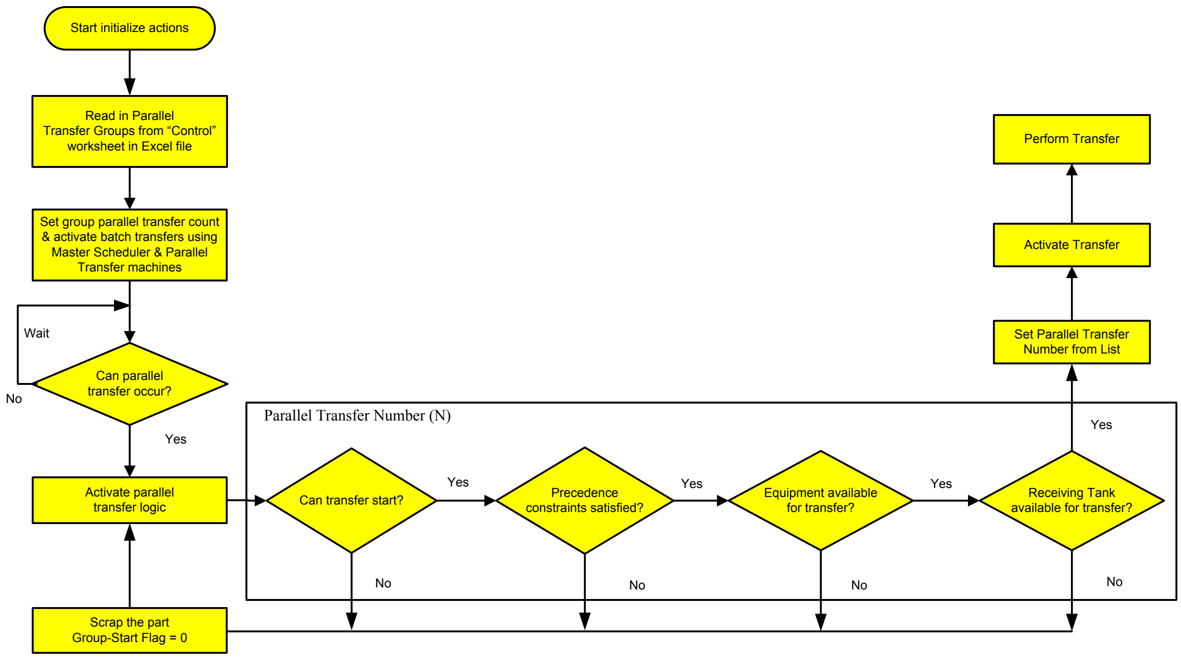

Figure 3:Flow Logic Diagram for Parallel Transfers

4.2.3 Transfer Routes & Equipment

At the start of the simulation, the model will read in the HTWOS transfer list and then read in the Primary and Alternative Transfer Routes listed in the model input file. After a transfer has been assigned by the Master Scheduler Machine, a cycle time (i.e. transfer volume divided by the flow rate) is set for the Sending Tank. Once the cycle time has been set, the Sending Tank Machine is activated using a Repair Function and the Receiving Tank Machine is deactivated using a Breakdown Function. The Pipe element is then activated using the Repair Function to allow the transfer of feed from the Sending Tank to the Receiving Tank. The Receiving Tank Machine and transfer route equipment machines are then activated using the Repair Function. The cycle times (i.e. volume divided by the flow rate) are then set and assigned to the Receiving Tank Machine and the transfer route equipment machines. The batch volume is then transferred from the Sending Tank to the Receiving Tank via the Pipe.

Once the batch transfer is complete, the Pipe element is deactivated using the Repair Function to stop the flow of material from the Sending Tank and the flow into the Receiving Tank. The Master Scheduler will then determine whether there are any further transfers to be made. If there are any further transfers, the Master Scheduler will assign the transfer to a Sending and Receiving Tank and the primary transfer route logic will repeat until all the transfers in the transfer list are complete. After the final transfer, the batch transfer sequence, transfer routes and equipment utilizations statistics are exported to an Excel output file.

4.2.4 Alternate Routes

If the primary transfer route is not available, e.g. if an item of equipment has failed during a transfer, the alternate transfer route algorithm is activated to determine whether an alternate transfer route is available. The alternative transfer route algorithm is run only for equipment that have expected restoration times more than 10 days. Figure 4 shows the model decision logic for alternative transfers.

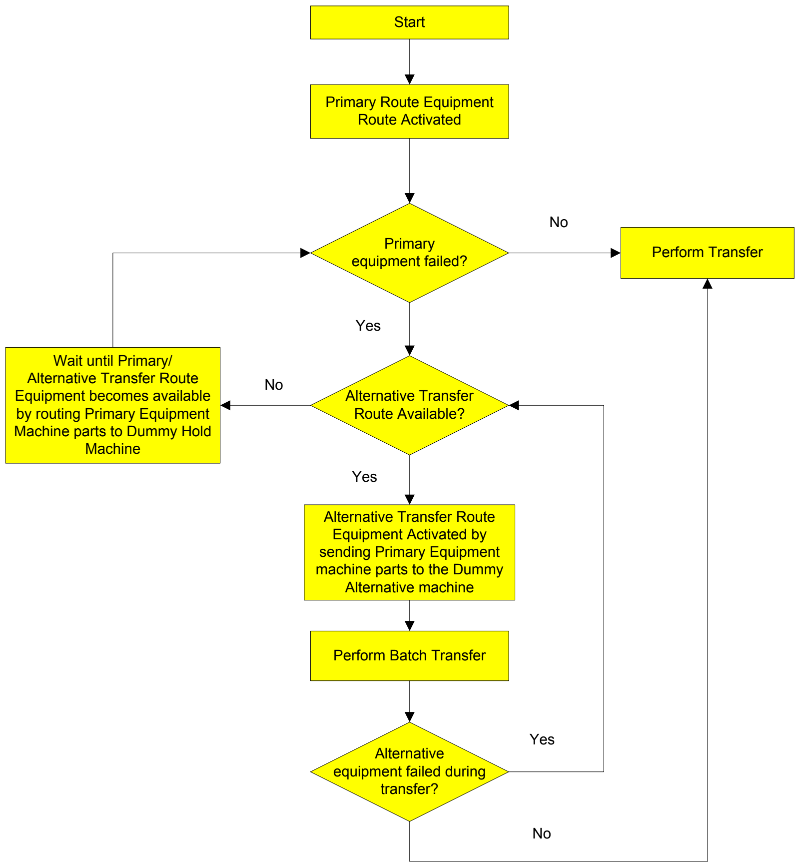

Figure 4: Flow Logic Diagram for Alternative Transfers

If an alternative transfer route is not available, the parts from the Primary Route Equipment machines are routed to Dummy Hold machines. The Dummy Hold machines will hold the parts until the alternative transfer route equipment or the primary route equipment becomes available. If an alternative transfer route is available, the parts from the Primary Transfer Equipment machines are routed to the Dummy Alternate Search machine which will identify the transfer route equipment that is required for the alternative transfer route. The Dummy Alternate Search machine then sends parts to the Alternative Transfer Equipment machines and the transfer will be performed.

4.3 Model Outputs

The Waste Feed Delivery OR model is setup to record a plethora of data to enable detailed analysis. Output data is categorized into four major Excel spreadsheets.

- Batch transfer sequence & Mission duration information
- Transfer routes used
- Equipment breakdown & repair Log
- Utilization statistics

5 PRELIMINARY RESULTS & ANALYSIS

Verification and validation activities were performed after model development to ensure that the Waste Feed Delivery OR Model met the intended requirements and produced results within an acceptable range. The Waste Feed Delivery OR Model results from the model run with no equipment RAM activated were checked against the HTWOS model output file that comprised the sequence of waste transfers over the mission. The model correctly simulated the sequence of the waste transfers based on precedence constraints and also produced a similar mission duration estimates to those predicted by the HTWOS model. The transfer delays included in the model were also checked on each transfer using the model log files and also deemed correct.

The model results from the preliminary model run with equipment RAM activated were checked by comparing the actual equipment downtime percentages from the model against hand-calculated equipment downtime percentages. Through this comparison, the model could be validated using downtimes reflective of those we would expect to see in the tank farms, thereby validating the model and providing confidence that results from this model will be comparable to actual system performance.

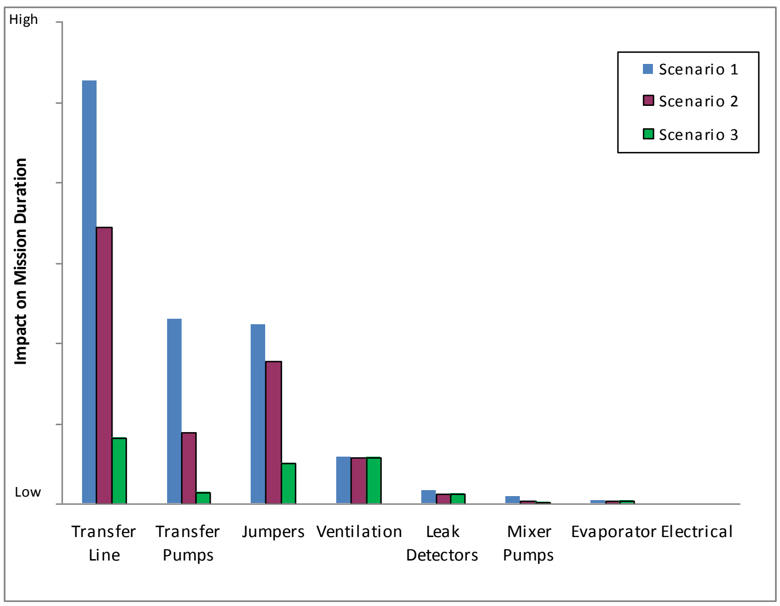

Figure 5: Preliminary Bottleneck Analysis

Several "what if" scenarios were performed using the preliminary version of the model to assess the impacts of RAM on Tank Farms performance and overall mission timescales. Each scenario was based on different maintenance strategy that could potentially be implemented in the Tank Farms.

For each scenario, a bottleneck analysis (Figure 5) was performed to identify which items of equipment had a high utilization and which items of equipment were the least reliable and had a significant impact on the mission. Initial results showed that the reliability of transfer lines, transfer pumps and jumpers had the biggest impact on the mission. These results will feed into the planning for future tank farm maintenance strategies and underpin critical spare parts lists. Similar analyses will be performed on the full scale model over the next several months. Confidence interval box plots and variance analyses will be employed to test for significance the comparative results produced from multiple scenario runs.

An analysis was also performed to determine the impact of transfer delays on mission length. Figure 6 shows the model results with and without alternative transfers based on a 95% confidence intervals and No RAM case is shown in Figure 6. This type of analysis isolates the effects (in this case of the alternate transfer logic) from the different operational aspects of the WFD system which would not be feasible without the OR model.

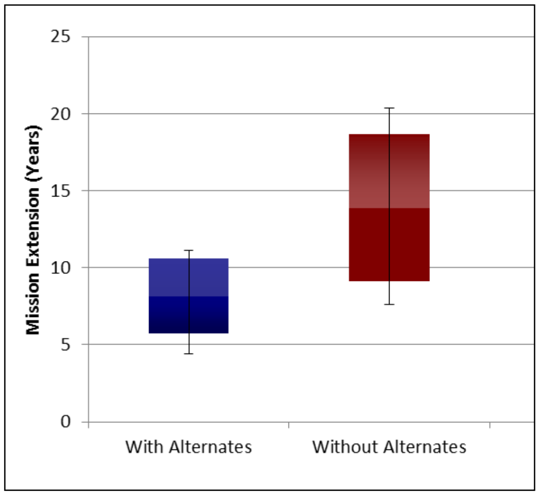

Figure 6: Mission Extension at 95% Confidence - With and Without Alternate Transfers

6 CONCLUSION

It is never too early in a project to develop OR models, and the effort required and return on investment should not be underestimated. Early model development identifies constraints on throughput, performance and operability at a time when the issues are easily resolved and the cost impact is less.

Development of additional modeling tools such as the Waste Feed Delivery OR Model will help mitigate operational risks and further improve long term planning confidence at the Hanford Tank Farms. The HTWOS system plan outputs together with the results from the Waste Feed Delivery OR Model will enable key decision makers to identify and mitigate reliability-related cost and schedule drivers. This knowledge will prepare the tank farms for safe and efficient operations, provide early equipment and resource management, reduce operations and maintenance costs and provide throughput and mission timescale assurance.

Results from the OR model will be used in conjunction with other studies to help identify possible areas for improvement in current tank farm maintenance strategies that could increase tank farms throughput and reduce mission timescales. Examples of future improvements that may be considered include identification of critical spare parts; required on-site maintenance capabilities; shift scheduling; and craft and labor availability.

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