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Changing the World's Energy Future

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Update on Parallel Process Execution in the Next Generation System Analysis Model

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INTRODUCTION

As of the end of 2022, it is estimated that over 90,000 metric tons of heavy metal (MTHM) of spent nuclear fuel (SNF) were stored at various commercial nuclear power reactor sites (both operating and shutdown) across the United States [1]. The Office of Storage and Transportation within the U.S. Department of Energy's Office of Nuclear Energy is planning for the transportation, storage, and eventual disposal of SNF and high-level radioactive waste (HLW).[1] To aid in this effort and inform decision-makers about the backend of the spent fuel cycle, systems analysis tools capable of analyzing the various options with respect to SNF and HLW management are being used as well as continuously improved to meet the evolving needs of the program. System analysts typically use these tools to vary underlying assumptions (shipping rates, available facilities, start dates, interim storage capacity, etc.) and study the associated system implications such as timing for clearing sites of SNF, various cost elements, transportation infrastructure acquisition needs, etc.

NEXT GENERATION SYSTEM ANALYSIS MODEL

Jointly developed by Argonne National Laboratory, Idaho National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories, the Next Generation System Analysis Model (NGSAM) is an agent-based simulation toolkit used for system-level modeling and analysis of the fuel cycle's backend [2]. NGSAM was originally based on the process analysis tool developed by the Department of Defense and the Federal Emergency Management Agency. One primary objective of NGSAM is to provide the analyst with the capability to model and analyze "what-if" scenarios within the integrated waste management system (IWMS). The IWMS combines knowledge and application from interdisciplinary fields such as transportation of radioactive material, consolidated interim storage of SNF, and geological waste disposal (Fig. 1). Successfully running an NGSAM scenario requires data from several sources; these include data from the unified database (UDB), the stakeholder tool for analysis of radioactive transportation (START), and the scenario-specific inputs provided by the analyst. The UDB is a structured query language database that stores information pertinent to SNF storage, transportation, and disposal. START is a web-based geospatial decision support tool used for planning SNF and HLW transportation and routing. Finally, the analyst defined inputs include SNF pickup logic, shipping rates from facilities, storage (or emplacement) capacity at facilities, shipping years, etc.

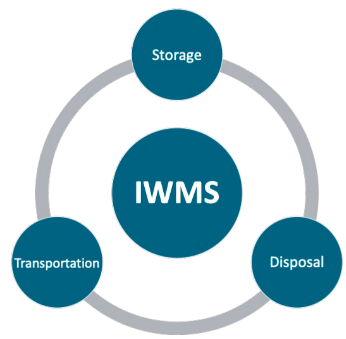

Fig. 1. Fundamental domains of the overarching IWMS [3].

TRANSPORTATION OPERATIONS

There are several steps that take place in an SNF transportation operation. The transportation operation is envisioned to start from the railcar fleet maintenance facility (FMF). This facility is assumed to be co-located with the drop-off site. A rail consist (along with empty transportation casks) departs from the FMF to the pickup site (e.g., a reactor site). (Note: cask cars along with the buffer cars and rail escort vehicles are collectively referred to as a rail consist.) If the pickup site does not have an operable rail line readily available, transload operations are performed at a transload site where the empty transportation casks are transferred from a rail consist to a barge, heavy haul truck, or a combination of both en route to the pickup site. At the reactor site, canisters are loaded in the transportation casks. These

[1] This is a technical paper that does not take into account contractual limitations or obligations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). To the extent discussions or recommendations in this paper conflict with the provisions of the Standard Contract, the Standard Contract governs the obligations of the parties, and this paper in no manner supersedes, overrides, or amends the Standard Contract.

This paper reflects technical work which could support future decision making by the Department of Energy (DOE or Department). No inferences should be drawn from this paper regarding future actions by DOE, which are limited both by the terms of the Standard Contract and Congressional appropriations for the Department to fulfill its obligations under the Nuclear Waste Policy Act including licensing and construction of a spent nuclear fuel repository.

transportation casks are then loaded back on the rail consist and depart for the drop-off site. Fig. 2 shows the process flow diagram of the anticipated transportation campaign. It is worth mentioning that in transload shipments both heavy haul trucks (HHTs) and barges can be used in the same campaign.

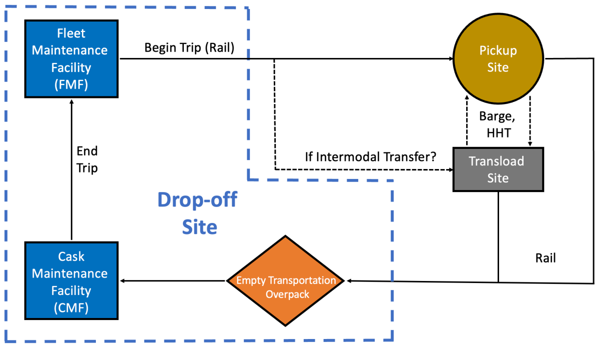

Fig. 2. A potential process flow diagram for SNF shipments assuming the drop-off site, CMF, and FMF are collocated.

Sequential and Parallel Process Execution

The sequence of operations has been captured in past site-specific de-inventory reports [4]. These reports utilized a sequential process execution methodology in developing the sequence of operations. For example, if there are two tasks that need to be accomplished, the second task is not assumed to start until the first task is completed in its entirety. In the case of SNF shipments, if the two tasks are assumed to be unloading empty transportation casks from railcars and loading canisters in these transportation casks, respectively, the reports assume that loading canisters in casks does not begin until all the transportation casks are unloaded from the railcar first. This was developed from a conservative standpoint; however, the de-inventory reports assert that some operations could be done concurrently to reduce time [4]. Parallel process execution takes inspiration from some lean construction principles that emphasize maximizing the efficiency of the resources [5]. In case of parallel process execution, the first canister is loaded in the transportation cask as soon as the casks are unloaded from the railcar—since two separate pieces of equipment are used for the operations (a crane for unloading the casks from railcars and potentially a horizontal or vertical cask transporter for performing the canister loading in the casks). Some notable advantages of implementing parallel process execution include:

- Increased SNF shipping capacity (MTHM/year) using the same transportation infrastructure
- Potentially speeding up site clearance.

There are several steps that take place in a typical transportation operation; these include:

1. Traveling from the FMF at the drop-off site to the pickup site
2. Unloading empty transportation casks (pickup site)
3. Loading the SNF canisters in the empty transportation casks at the pickup site
4. Loading the casks (with the SNF canisters) on the railcars at the pickup site
5. Traveling from the pickup site to the drop-off site
6. Unloading the casks and canisters at the drop-off site
7. Extracting the canisters from the casks at the drop-off site
8. Performing any maintenance activities on the casks (if needed) at the CMF
9. Performing rail, buffer, or escort car maintenance (if needed) at the FMF
10. Loading the empty transportation casks back on the railcars at the drop-off site.

It is worth mentioning that additional steps must be considered for routes requiring transload operations. Some underlying system/transportation assumptions used in this work include:

1. Using a seven-car rail consist with two buffer and one escort car in most scenarios
2. Shipping to a single destination
3. Assuming all the required infrastructure, equipment, physical area, and human resources are readily available
4. Assuming the use of a vertical or horizontal cask transporter for loading or unloading a canister in a cask
5. Assuming the use of a crane to load/unload a cask from the railcar
6. Assuming a barge can accommodate two HHTs, and a towboat can pull four barges
7. Assuming a maximum of seven HHTs are available at the transload site
8. Assuming the reactor site (generally the pickup site), transload site, and the drop-off site operate at 8 hours, 8 hours, and 16 hours per day, respectively.

Fig. 3 shows the concept of sequential and parallel process execution visually. We assume three tasks; unloading casks from a railcar, loading canisters in casks, and loading casks on railcars depicted by blue, green, and orange, respectively. (Note: reader is referred to the web version of the article for interpretation of color.) In sequential process execution, a task does not begin until the previous task is completed in its entirety. In parallel process execution we have some tasks taking place simultaneously thereby reducing the overall transportation operation time.

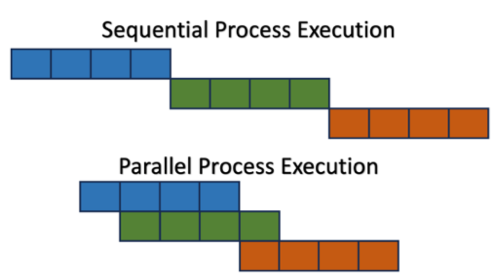

Fig. 3. Sample illustration of sequential and parallel process execution.

In this work, one of the aims is to examine the turnaround time for sequential and parallel process execution for various scenarios. Turnaround time is defined as the time between two consecutive rail shipments from the FMF to the pickup site (assuming a single consist). A short turnaround time for a shipment implies that a greater number of shipments can be carried out with the same transportation infrastructure in a given time frame. This work explores the implications of parallel process execution in four scenarios:

1. Rail-only shipments
2. Rail with barge transload
3. Rail with heavy haul truck(s)
4. System-wide U.S. fleet analysis.

Rail-only Shipments

This section explores the differences between sequential and parallel process execution for reactor (pickup) sites that can readily be accessed using rail infrastructure. It is assumed that this rail consist has seven vertical casks. Travel to a reactor site is dependent on the distance between the drop-off and the reactor sites. It is assumed to take 4 hours per transportation cask to unload an empty cask from a railcar at a reactor site. Loading a canister in a transportation cask is assumed to take 16 hours per cask. Loading the casks (along with the SNF canister) onto the railcar is assumed to take 4 hours per cask. The next step is traveling to the drop-off site and is dependent on the distance. At the drop-off site, unloading the transportation casks is assumed to take 4 hours per cask. In addition, NGSAM assumes 8 hours for any additional checks for the casks or railcars after travel to the drop-off site irrespective of the number of casks being shipped. Extracting the canister from the cask is assumed to take 16 hours per cask. The empty transportation casks are then loaded back on the railcars (approximately 4 hours per cask). In this work, it is assumed that the casks and rail consist do not undergo any maintenance activities. Table I shows the process steps along with the number of hours each step should take.

Table I. Time per Step for a Rail Shipment with 7 casks

Step #	Process Step	# of Hours
1	Travel to the pickup site	Scenario dependent
2	Unload empty casks †	28
3	Load canisters in casks †	112
4	Load casks on consist †	28
5	Travel to drop-off site	Scenario dependent
6	Unload casks (and canisters) ‡	36
7	Extract canister from casks ‡	112
8	Load casks on railcar ‡	28

†Pickup site; ‡drop-off site

The number of days it takes for each activity at a given location is rounded up. For instance, in Table I, it takes 28 hours to unload empty casks at the pickup site. Since this facility operates 8 hours a day, this step takes 4 days to complete. Similarly, this yields a total of 22 days at the reactor (pickup) site and 12 days at the drop-off site. Therefore, the turnaround time for this shipment using sequential process execution is 34 days (plus any additional travel time). It is worth mentioning that the same process step times are assumed for all four scenarios covered in this work.

While performing tasks in parallel, several process steps are envisioned to be performed simultaneously; therefore, the total number of hours at a facility (pickup site or drop-off site) is used to estimate the number of days rather than the time for each process step (like in sequential process execution). This yields 15 days at the reactor (pickup) site and 8 days at the drop-off site. Thus, the turnaround time for this scenario is estimated to be 23 days plus any travel to and from the FMF. So, excluding any travel time, parallel process execution in this scenario led to a reduction of about 11 days in process time (32.4%).

Rail with Barge Transload

In certain scenarios, a reactor (pickup) site might not have a rail line to pick up SNF via a rail consist. Even if a rail line exists, it might not be in an operable condition. In such cases, an intermodal transfer option using barge, HHTs, or a combination thereof may be employed. In this scenario, we will explore a rail consist shipment via a transload operation using barges. For this work, it is assumed that a towboat can accommodate four barges and a single barge can accommodate two casks. The intermodal transfer time for casks between rail to barge (as well as barge to rail) is 4 hours per cask. The rail consist starts from the FMF and reaches the transload site. At this transload site, the empty transportation casks are loaded on the barges. Assuming a single crane is performing this task, the casks are loaded on the barges, one at a time. Transload sites are assumed to operate for 8 hours a day. Once the barges are loaded with the empty transportation casks, the towboat departs for the reactor (pickup) site. At the pickup site, empty casks are unloaded from barges, the canisters are loaded into casks, and the casks are subsequently loaded back on the barges. Once all the seven casks are loaded on the barges, the towboat departs for the transload site where the loaded casks are transferred from the barges to rail cars. Once the cask cars are loaded with casks, the rail consist departs for the drop-off site. At the drop-off site, steps 6, 7, and 8 (Table I) are performed, and the consist is prepared for the next transportation run.

As for the turnaround time, the additional steps that take place at the transload site must also be considered. This equates to 28 hours (at 4 hours per cask). This results in 4 days of transload operations; since in this transportation run, two transload operations are required leading to 8 additional days in the turnaround time compared to the rail-only shipment. Therefore, in a sequential execution scenario, the turnaround time is estimated to be 42 days (excluding travel time). If parallel process execution were to be implemented, the turnaround time (excluding travel) for this scenario is estimated to be 31 days (a 26.2% reduction in turnaround time).

Rail with Heavy Haul Truck(s)

Heavy haul truck transload operations are sometimes preferred over barge transloads due to the existing infrastructure on and near the pickup sites. It is assumed to take 4 hours to transload a cask from a rail to a heavy haul truck (and vice versa). Generally, a single cask is accommodated on a heavy haul truck, and it is assumed that the required number of HHTs (seven) is available at the transload sites. The implications of using a single heavy haul truck in transload operations as well as intermodal transportation in general were explored in prior work [6, 7]. The transload site is also assumed to operate 8 hours a day. Therefore, this scenario is similar to the "Rail with Barge Transload" scenario. This yields a turnaround time (excluding travel) of 42 and 31 days for sequential and parallel process execution using HHT transload, respectively.

System-wide U.S. Fleet Analysis

The previous three scenarios explored the implications of turnaround time on a single shipment using the respective mode(s) of transportation. A reduction in the turnaround time was observed while using parallel process execution. The next step is to expand this analysis to a U.S.-fleet-wide scenario to understand the implications on the number of packages that are picked up. For this analysis, seven rail consists (each with seven cask cars) were used, and the shipping start date was set to 2060. It was further assumed that a barge can accommodate two HHTs or two casks at a given time. Fig. 4 shows the cumulative normalized packages shipped as a function of years for sequential and parallel process execution. It can be observed that parallel process execution leads to a greater shipping rate for a given transportation fleet size. A maximum difference of 30% is estimated for the cumulative normalized packages shipped between sequential and parallel processing in this scenario.

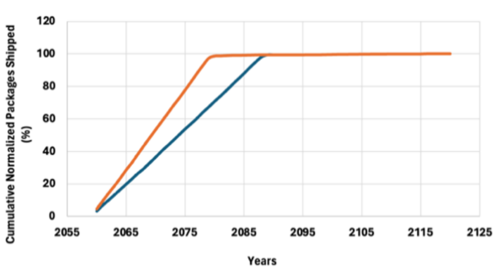

Fig. 4. Cumulative normalized package shipments for sequential and parallel process execution.

CONCLUSIONS

This work initially provided an overview of the NGSAM tool, a description of the high-level steps in transportation operations, and an illustration of the differences between sequential and parallel process execution. The changes in turnaround times while using sequential and parallel processing for the three shipping modes were covered. On average, using parallel processing resulted in greater than 25% reduction in process time. This analysis was also conducted at a system level, and a maximum difference of 30% in cumulative normalized packages shipped was observed between sequential and parallel process execution. This demonstrated the potential advantages of using parallel process execution in direct rail as well as intermodal transportation options.

REFERENCES

1. Pacific Northwest National Laboratory (PNNL), CURIE Resource Portal for DOE Nuclear Waste Management Information, Map accessed May 28, 2024, https://curie.pnnl.gov/map.

2. R. JOSEPH et al. The Next Generation System Analysis Model: Capabilities for Simulating a Waste Management System - 19131. United States: N. p., 2019. Web.

3. R. JOSEPH et al., "Transportation and Systems Analysis Collaborations in Support of a Federal Consolidated Interim Storage Facility," (2024); https://doi.org/10.48550/ARXIV.2403.18861.

4. AREVA FEDERAL SERVICES LLC, "Initial Site-Specific De-Inventory Report for Trojan," (2016); https://www.osti.gov/servlets/purl/1582066.

5. R. F. AZIZ and S. M. HAFEZ, "Applying lean thinking in construction and performance improvement," Alexandria Engineering Journal 52 4, 679 (2013); https://doi.org/10.1016/j.aej.2013.04.008.

6. H. GADEY, L. V. WAL, and R. JOSEPH, "Implementation of Parallel Process Execution in the Next Generation System Analysis Model," (2024); https://doi.org/10.48550/ARXIV.2403.09848.

7. H. R. GADEY et al., "System Analysis Modeling and Intermodal Transportation for Commercial Spent," (2023); https://doi.org/10.48550/ARXIV.2306.02446.