Optimization Scheme for Establishing Queues for Shipment of UNF from Shutdown Reactor Sites – 17554

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ABSTRACT

Approximately 14, 815 used nuclear fuel assemblies (5,800 MTHM) are stored in 486 dry storage cask systems located at 12 independent spent fuel storage installations (ISFSIs) located at shutdown reactor sites located across the U.S. that have no access to spent fuel pools. A preliminary evaluation was performed by the University of North Carolina at Charlotte (UNCC) in collaboration with AREVA to establish optimization schemes for establishing queues for the removal of this used/spent nuclear fuel (hence forth identified as UNF) and Greater than Class C low level wastes (GTCC) found at these shutdown reactor sites. These queues assumed the major portion of the shipment of the UNF and GTCC would be by rail, with heavy haul truck or barge potentially utilized to move the UNF from the site to rail for sites not served directly by rail. The destination for these rail shipments were a hypothetical consolidated interim storage facility (CSF) located in West Texas. The queues were developed based on the total costs and time to finish all shipments needed to remove all the UNF from these shutdown sites. Results are presented for optimization schemes based on a continuous flow of shipments using 1, 2, and 3 crews dedicated to individual ISFSIs and discrete shipments using 2 crews capable of performing operations at multiple ISFSIs.

INTRODUCTION

The 12 ISFSIs located at shutdown reactor sites considered in this analysis are listed in Table 1. These sites have no access to spent fuel pools and for almost each one of them, the ISFSI is the only remaining vestige of the nuclear facilities that once populated the sites. Hence, emptying these sites of the UNF and GTCC will allow them to be re-utilized and furthermore, would allow for the consolidation of the security and monitoring of these systems (or the disposal of these systems – if compatible with the disposal media). According to the Department of Energy's (DOE) Standard Contract (10CFR961), the acceptance priority for UNF from civilian nuclear power reactors shall be based upon the age of the UNF as calculated from the date of discharge of such material from the reactor. The oldest fuel will have the highest priority for acceptance, however priority may be accorded any UNF removed from a civilian nuclear power reactor that has reached the end of its useful life or has been shut down permanently for whatever reason. The 12 ISFSIs listed in Table 1 and shown in Figure 1 fall into this shut down category. However there is no clear guidance on how the acceptance priority for these shut down sites should be ordered (date of discharge, date of shutdown, etc.). In this evaluation, some leeway was taken from the oldest fuel first approach to instead allow for these 12 ISFSIs to be prioritized into queues based on a bi-objective optimization model that considers two objectives, total shipment costs and time to finish all shipments. This model allowed optimization on the following parameters: the number of transportation casks, the number of cask railcars, the sequence of sites to be transported from, and the shipment schedule for each site.

Table 1: ISFSIs Located at Shutdown Reactor Sites

Site ID	Site Name	# of Systems	Transportation Cask System	Cask Family ID
1	Yankee Rowe	16	NAC-STC	2
2	Connecticut Yankee	43	NAC-STC	2
3	Maine Yankee	64	NAC-UMS UTC	1
4	Zion	65	MAGNATRAN	7
5a	Kewaunee-1	14	MP197HB	8
5b	Kewaunee-2	26	MAGNATRAN	7
6	Rancho Seco	22	MP187	5
7	Trojan	34	HI-STAR 100	6
8	Crystal River	41	MP197HB	8
9a	San Onofre-1	18	MP187	5
9b	San Onofre-2&3	124	MP197HB	8
10	Humboldt Bay	6	HI-STAR HB	6
11	Big Rock Point	8	TS125	4
12	La Crosse	5	NAC-STC	2

METHOD

To establish shipping queues from the 12 ISFSIs listed in Table 1 to the CSF located in the hypothetical destination of West Texas, a two-step optimization method consisting of two respective mixed integer programing (MIP) models were utilized. In the first step, Model (1) determines the optimal number of transportation casks and railcars to purchase that minimizes the total cost and time of shipping UNF from each site. Subsequently in the second step, Model (2) provides a shipment schedule, on a yearly basis, that completes all sites within an estimated time frame (output from Model (1)) and satisfies the yearly inflow assumed constraint of 1500 MTHM at the CSF. This problem setting resembles a job scheduling problem on identical parallel machines (i.e., crew teams). Details of the models are found in [1]. Model (1) determines the number of transportation casks for each cask family ID, the number of railcars, and assignment of sites to crew teams in order to optimize the cost as well as the total estimated time to complete shipments from all sites. After the solution to Model (1) is obtained, Model (2) is formulated and solved to determine a feasible shipment schedule for each crew team by utilizing an assumed annual 1500 MTHM receipt limit at the CSF. CPLEX Solver was used to solve Model (1) and Model (2).

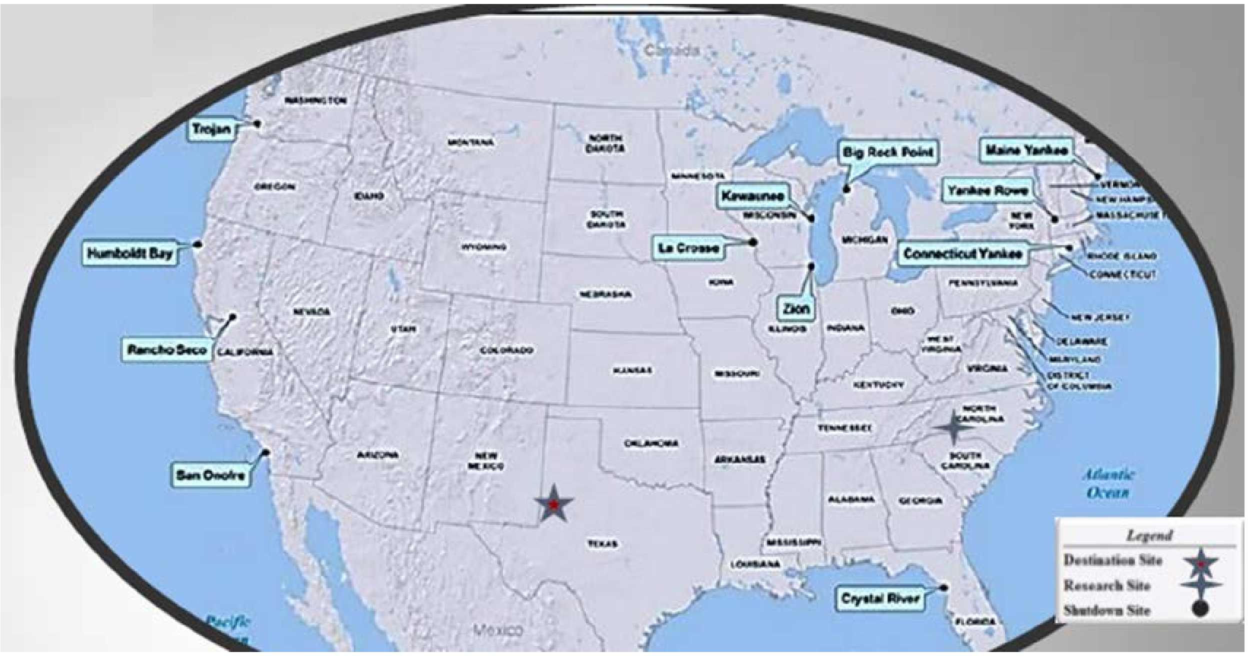

Figure 1: Location of 12 ISFSIs with Shutdown Reactors Considered in this Assessment

“Transportation Routing Analysis Geographic Information System” (TRAGIS) was utilized to provide routing simulations and information regarding the specific locations of the rail spurs utilized to load the UNF from the 12 ISFSIs and subsequently ship them to the hypothetical destination in West Texas (see Figure 2). For these routes, TRAGIS provided distance, time durations, and population density utilized in the optimizing of the route and the costing of transportation activities needed to ultimately optimize the shipping queue. An analytic hierarchy process (AHP) was utilized to determine which route alternative is best relative to distance traveled, time expended to ship (both directly proportional to cost in this assessment), and population density traversed.

Cost inputs to these models were developed based on some initial assessments for unloading the UNF from some specific sites (Connecticut Yankee, Big Rock Point, and Humboldt Bar) and extrapolated to the other sites considering: number of casks stored at each of these sites, the cask family type stored at each site, the access of each site to rail, location within the country, etc. Table 2 identifies the breakdown of the costs established in this assessment. Learning curves were also utilized to decrease labor cost as the number of shipments performed increased. In general, a 6 day loading scheme onto a cask railcar and a 1 day unloading scheme at the CSF per transportation cask was utilized to assess the below costs.

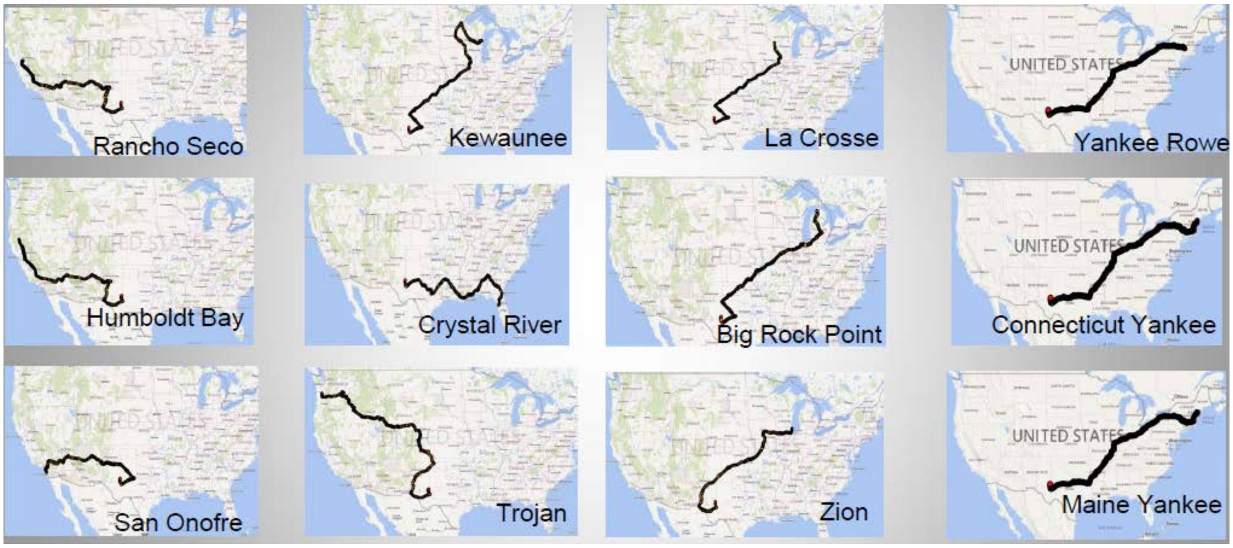

Figure 2: Routes Established by TRAGIS for Each of the 12 ISFSIs Considered in this Assessment

Table 2: Cost Breakdown

Transportation Cost	Equipment Cost	Resource Cost
Heavy Haul Rate	Heavy Haul Crane Unit	Project Manager
Railway Travel Rate	Large Forklift	Plant Manager/Coordinator
Roadway Travel Rate	Man Basket	Shift Lead
Security Rate	Welding Machines	Radiation Survey
Satellite Communication Rate	Miscellaneous Supplies	Transport Coordinator
Stateline Fees	Transload Lighting	Quality Assurance Support
Mobility In/Out	Transload Fencing	Cask Supervisor
Load/Unload Rates	Goldhofer Trucking	Transport Analyst
Goldhofer Transload		Engineering Support
Class II to Class I Rail		Heavy Haul Crew
		Rail Security Crew

In addition, the models utilized some constraints to reasonably manage the solution space including: (1) a maximum number of transportation casks for a specific cask family of 10 was considered; (2) sites with the same cask family cannot ship at the same time; (3) the number of cask rail cars is equal to the total number of transportation casks purchased and limits the shipment rates from each site; and (4) the receipt rate of 1500 MTHM/yr was conservatively assumed for the CSF.

RESULTS

Results from Model (1) are shown in Table 3, which show the optimized, approximate costs and time for moving all the UNF from the 12 ISFSIs identified in Table 1 to a CSF. The alpha (α) parameter establishes the level of importance of the cost over time duration to perform all the shipments. For example, if the goal is to minimize the costs associated with performing these shipments, then α = 1 and costs would be ~$450 million but would take approximately 21 years to complete. If minimizing time is important, then α = 0 and the duration would be approximately 8.7 years to perform. The AHP established a mean value of α = 0.6 (favoring cost over time) would be used throughout this assessment. At this value, Model (1) established 15 cask rail cars and 2 crews to perform the shipment activities at the 12 ISFSIs would be optimal ($567 million and 10.5 years). If only 1 crew were utilized, then Model (1) established approximately $582 million, 20.5 years, and 9 cask rail cars would be optimal and if 3 crews were utilized then $573 million, 7.4 years, and 19 cask rail cars would be optimal. Model (1) also established the number of transportation casks by cask family would be optimally needed to meet these schedules.

Table 3: Results from Model (1) based on Importance of Cost (α=1) and Time (α=0)

Alpha (α)	Approx. Total Cost ($)	Approx. Total Time (days)
0.0	$1,260,124,550	3178
0.1	$1,055,869,937	3184
0.2	$ 847,179,828	3295
0.3	$ 718,328,655	3465
0.4	$ 622,521,931	3658
0.5	$ 583,046,012	3780
0.6	$ 567,300,000	3840
0.7	$ 512,965,168	4205
0.8	$ 471,271,501	4626
0.9	$ 466,170,680	4729
1.0	$ 446,654,495	7749

Model (2) took the results from Model (1) to establish the queue for the optimal shipment of the UNF from the 12 ISFSI sites. Table 4 shows the results (the queue) from Model (2) for the case α = 0.6. In order to examine the improvement of these models over the oldest fuel first (OFF) approach, the same cost and travel route parameters utilized to perform the above assessment were applied to the OFF approach. The OFF approach resulted in a cost of approximately $582.2 million and shipment duration of 20.6 years. So the optimized queue identified in Table 4 results in a nominal cost savings of ~4%, but ~10 fewer years to perform the shipments. Table 5 show queues for the shipment of UNF from these 12 ISFSIs given different numbers of crews and shipment on a continuous bases from each ISFSI until an ISFSI has been emptied and for an optimized discrete basis using 2 crews.

Table 4: Model (2) Results for the Sequence of Shipments from the 12 ISFSIs

Site ID	Year(s) of Shipment	Site ID	Year(s) of Shipment
1	7	7	3,4
2	6,7	8	2
3	1,2,3	9a	1
4	5,6	9b	3,4,5
5a	1	10	1
5b	7	11	8
6	8	12	1

Table 5: Queues for Different Shipment Models and Crew Numbers

Order of Sites by Crew and Model							
Continuous Model						Discrete Model	
1 Crew	2 Crews		3 Crews			2 Crews	
A	A	B	A	B	C	A	B
10	10	6	3	10	9b	5a	6
12	12	7	4	12	8	9b	11
6	1	3	5b	6	5a	12	3
1	2	11		1		10	5b
7	9b	4		7		1	9a
2	8	9a		2		8	7
3	5a	5b		11		2	4
11				9a			
4							
8							
5a							
5b							
9a							
9b							
20.6 yr	9.6 yr	10.5 yr	6.9 yr	6.8 yr	7.4 yr	9.5 yr	10.5 yr
$582M	$567M		$573M			$567M	

CONCLUSIONS

In this assessment, examination of optimizing the queues for the shipment of UNF from 12 ISFSIs associated with shutdown reactor sites based on optimizing the costs and the shipment schedule was performed utilizing a two-step method. The first step solves a bi-objective optimization to minimize both time and cost, while the second step solves a mixed integer program to determine shipment schedule. Optimal queues based on these activities were established considering differing crew numbers and site emptying models (continuous vs. discrete). For these 12 ISFSIs, no significant difference was found between the emptying models, but some significant time savings over an OFF approach could be established by the model. Future improvements to the model include refinement of the cost estimates and potential inclusion of other factors impacting the queue including, but not limited to: savings due to crew working on common cask families, potential self-funding mechanisms based on collected monies owed to DOE, availability of transportation casks and associated equipment (e.g., impact limiters), potential savings from law suits (e.g., Judicial Fund), potential future uses of ISFSI land, ease of shipping the UNF (e.g., available on-site rail spur), and political influence.

REFERENCES

[1] Richard Alaimo, William Cole, Justin Ervin, Hanna Tannous and Kevin Wong, “Optimization of Used Nuclear Fuel Shipments”, Institute of Industrial & Systems Engineers, Operations Research Division, Paper ID: 1345.