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TRANSPORTATION OPERATIONS MODEL ANALYSIS FOR THE REMOVAL OF STRANDED FUEL FROM SHUTDOWN REACTORS

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ABSTRACT

The Transportation Operations Model was used to identify options for removing stranded fuel currently in dry storage at nine shutdown reactor sites to a hypothetical consolidated storage facility. The logistical variables included the campaign duration, fuel selection priority, consist size, and location of the consolidated storage and maintenance facilities. The major factors affecting the logistics of fuel removal were identified. Recommendations for optimal strategies for the transport of stranded fuel are made.

INTRODUCTION

There are nine shutdown (decommissioned) reactor sites in the U.S. with stranded used nuclear fuel (UNF) and greater-than-Class C (GTCC) waste in dry storage. One option under consideration for removing the UNF from these sites is to ship the UNF to a consolidated storage facility. At the present time, neither the location of a consolidated storage facility or the specifics of de-inventorying scenarios are not defined. A hypothetical case study presented in Kalinina et. al (2013) considered a number of different de-inventorying scenarios and potential repository locations and identified major factors affecting the scenario performance. The study presented in this paper is a continuation of this work, but with the focus on the concurrent regional de-inventorying scenario. This scenario considers de-inventorying of the Eastern, Midwestern, and Western sites in three concurrent regional campaigns: Both, scenario and associated assumptions are hypothetical. The purpose of this study was to explore the logistics and costs associated with this option.

METHOD

The analysis was done with the Transportation Storage Logistics (TSL) model (Nutt, 2012). TSL is the merger of the existing modeling codes TOM (the Transportation Operations Model) (Busch, 2012) and CALVIN (the CRWMS Analysis and Logistics Visually Interactive tool) (Nutt, 2012). The modeling of the transportation scenarios was performed using the TOM component of TSL.

TOM calculates the resources (casks and vehicles) required for meeting the defined de-inventorying scenario, the timing of each trip (its transportation cycle), and all associated costs. Each calculation is done for an assumed location of the consolidated storage facility, cask maintenance facility and the fleet maintenance facility.

TOM provides two options in defining the maximum consist size, i.e., the maximum number of casks to be shipped at a given time. In the first option, the maximum consist size is applied to all the sites. In the second option, the site-specific consist size is defined for each site. The maximum consist size is used to determine the number and sizes of consists that will be used for each site in each year. TOM builds as many of the largest-sized consists permitted at the pickup site as possible, and then adds another less-than-maximum-sized consist to move the remaining casks.

The duration of each trip is calculated based on the transportation routes (the rail, road, and waterway links). If this information is not available from the TOM database, TOM obtains it via an external route generation program.

After each trip is defined in terms of consist size and trip duration, TOM uses this information to calculate the rolling stock and cask schedule that efficiently uses the casks, escort assets, transportation assets, and loading opportunities at the pickup site.

The calculated transportation fleet and schedule are the input parameters for the cost calculations. Costs in TOM are separated into three following categories.

- Capital costs include the acquisition and disposal of casks and rolling stock. The cost of acquisition occurs in the year that the acquisition takes place.
- Maintenance costs are incurred whenever inspection is done on the casks and rolling stock. These happen at the end of each transportation cycle.
- Operations costs include transportation asset operations, leased cask handling equipment, 180c charges, and security personnel costs.

The majority of the input parameters used in TOM calculations are defined in the TOM database. These include the locations of the reactor sites, the empty and loaded weight of the casks, the length of time to load and unload the casks, the duration of inspections, and the cask and rolling stock costs.

TOM assumes that a consist needs to arrive with transportation overpacks into which the canisters will be loaded. All of the canisters at all of the stranded sites already have a specific transport overpack designated for the transport of the canisters. These transport overpacks have been designed and have received NRC Certificates of Compliance. The exception is the Humboldt Bay site, where the fuel is already in transportation casks. In this case, TOM uses the existing transportation casks.

More details regarding TOM calculation method, associated assumptions, and input parameters can be found in Kalinina et. al (2013).

INPUT PARAMETERS

The major input parameters into the transportation calculations are inventory, de-inventorying scenario and locations of the consolidated storage facility and cask and fleet maintenance facilities. Note, that these parameters, except inventory, are hypothetical.

The UNF at the shutdown sites is stored in canisters within the storage overpacks. Consequently, the initial conditions of this analysis are the site-specific inventory and type of canisters in which this inventory is stored. This information is summarized in Table 1.

Four locations for the hypothetical consolidated storage facilities were considered: Southeastern USA, Southwestern USA, Northwestern USA, and Northeastern USA. The maintenance facilities were co-located with the consolidated storage facility.

The de-inventorying scenario was defined as follows for the case in which Eastern, Midwestern, and Western sites are assumed to be unloaded in three concurrent regional campaigns.

1. De-inventory Main Yankee using 5-car consist via direct rail. At the same time, de-inventory Yankee Rowe using 2-car consist via heavy haul truck to rail and direct rail. After de-inventory of Yankee Rowe, de-inventory Haddam Neck (Connecticut Yankee) using 4-car consist via barge to rail and direct rail.
2. De-inventory Zion using 5-car consist via direct rail. At the same time de-inventory Big Rock using a 1-car consist via heavy haul truck to rail and direct rail. After Haddam Neck is de-inventoried, de-inventory La Crosse using 4-car consist via direct rail.
3. De-inventory Trojan using 4-car consist via direct rail. At the same time, de-inventory Rancho Seco using 2-car consist via direct rail and de-inventory Humboldt Bay using 1-car consist via heavy haul truck to rail and direct rail.

Table 1. Used Nuclear Fuel Inventory Stored at Shutdown Sites

Site	Fuel Type	Storage Canister	Capacity	NN of Canisters	Type of Transportation Overpack
Big Rock Point	BWR	W150	64	8	TS-125
Haddam Neck	PWR	MPC-26	26	40	NAC-STC
Maine Yankee	PWR	UMS-24	24	60	NAC-UMS
Yankee Rowe	PWR	MPC-36	36	15	NAC-STC
Rancho Seco	PWR	24PT	24	21	MP187
Trojan	PWR	MPC-24E/EF	24	34	HI-STAR 100
Humboldt Bay	BWR	MPC-80	80	5	HI-STAR 100
La Crosse	BWR	MPC-LACBWR	68	5	NAC-STC
Zion 1 and 2	PWR	TSC-37	37	61	NAC-MAGNATRAN

NOTE: These data are from (Leduc, 2012)

The de-inventorying schedules were developed based on the above scenario description for 2 campaign durations – 4 years and 7 years. In addition to the sequence defined above (E-MW-W), five other possible sequences were considered for the 4 year campaign: E-W-MW; MW-E-W, MW-W-E; W-E-MW; W-MW-E. A specific de-inventorying (pickup) schedule was developed for each sequence.

Finally, the site specific consist sizes defined above were substituted either with the 2-car consist or 3-car consist for all the sites for the case with the E-MW-W sequence.

40 cases (7 de-inventorying schedules) were considered for the concurrent regional scenario:

- 24 cases considered 6 different sequences (and corresponding schedules) assuming a four year campaign and 4 different consolidated storage locations.
- 4 cases considered E-MW-W sequence for the 7 year campaign and 4 different consolidated storage locations.
- 4 cases considered E-MW-W sequence for the 4 year campaign, 2-car consist and 4 different consolidated storage locations.
- 4 cases considered E-MW-W sequence for the 4 year campaign, 3-car consist and 4 different consolidated storage locations.
- 4 cases considered E-MW-W sequence for the 7 year campaign, 2 car-consist and 4 different consolidated storage locations.

One special case was considered in addition to the concurrent regional de-inventorying scenario. This case was developed with the intent to produce the lowest total cost of de-inventorying and, as such, is entitled optimized de-inventorying scenario. The information on the major factors affecting the total cost was used to develop the pickup schedule for this case. This case is strictly hypothetical and was meant to put a low bound on the cost estimate analysis for the 7 year campaign. 4 cases were considered for this scenario, one for each of the 4 different consolidated storage locations.

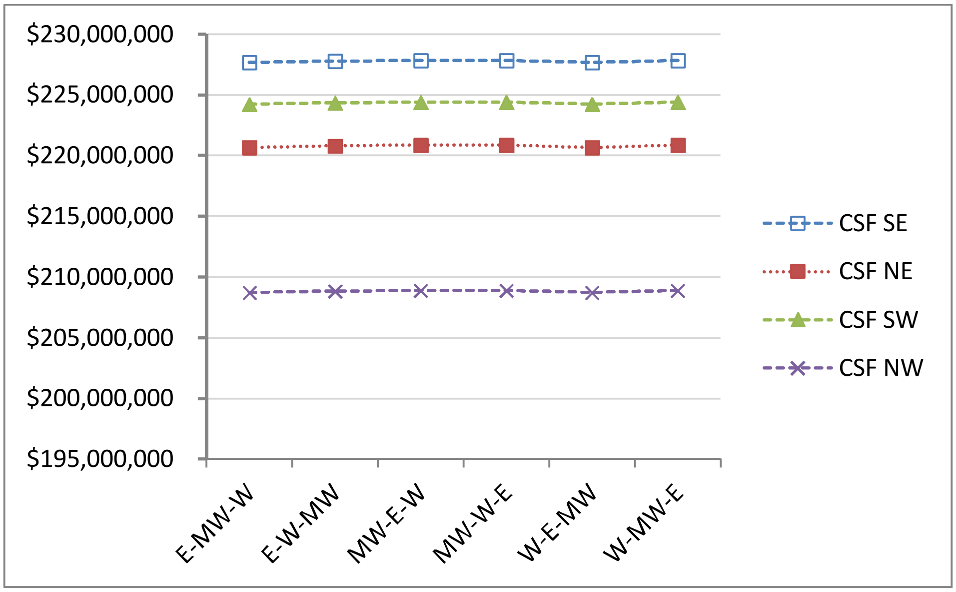
RESULTS

Transportation calculations were done for each of the 40 cases defined above. The output of each TOM run included the detailed schedule of all the transportation activities for the duration of campaign, trip report, cost report, and acquisition report. The results of these analysis are discussed below.

De-Inventorying Sequence as a Factor in Concurrent Regional Campaign

24 cases considered 6 different de-inventorying sequences in a four year concurrent regional campaign scenario for 4 different consolidated storage locations. The results are shown in

Figure 1. The sequence in which the different regions are de-inventorying has negligible impact on the total cost. The total cost ranges from 209 Million (consolidated storage in NW region) to 228 Million (consolidated storage in SE region).



NOTE: CSF is Consolidated Storage Facility

Figure 1. Total Cost as a Function of De-inventorying Sequence in Concurrent Regional Campaign.

<u>Consolidated Storage Location as a Factor in Concurrent Regional Campaign</u>

The total cost in the concurrent regional 4 year campaign is shown in Figures 2 to 3 for the different cases considered in this scenario. The consolidated storage location has moderate impact (maximum 9%) on the total cost.

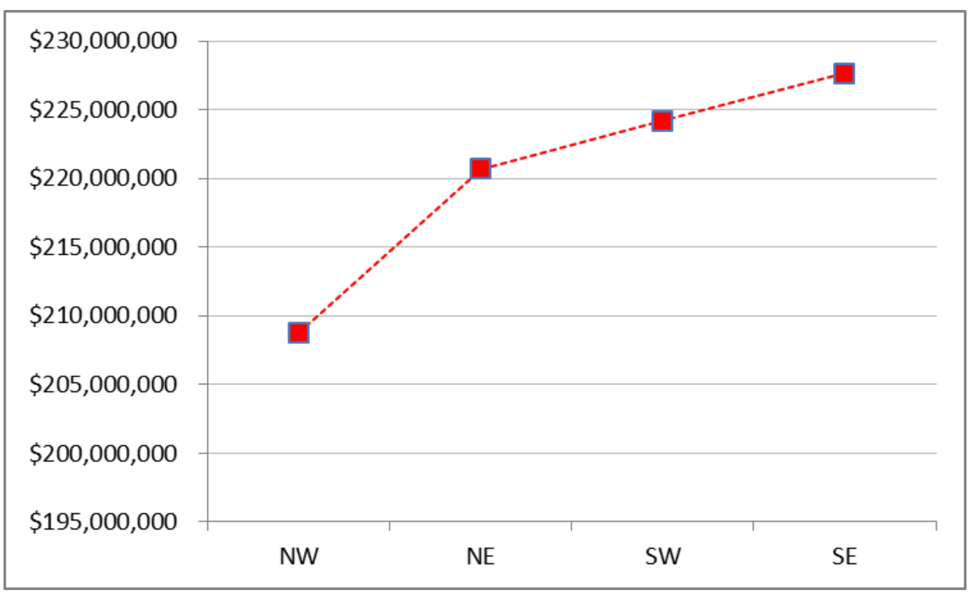


Figure 2. Total Cost (Regional Sequence Average) as a Function of Consolidated Storage Location.

<u>Campaign Duration as a Factor in Concurrent Regional Campaign</u>

The 4 year campaigns are compared to the 7 year campaigns in Figure 3. The impact on the total cost is very small (1%). The total cost is slightly higher in the 7 year campaigns.

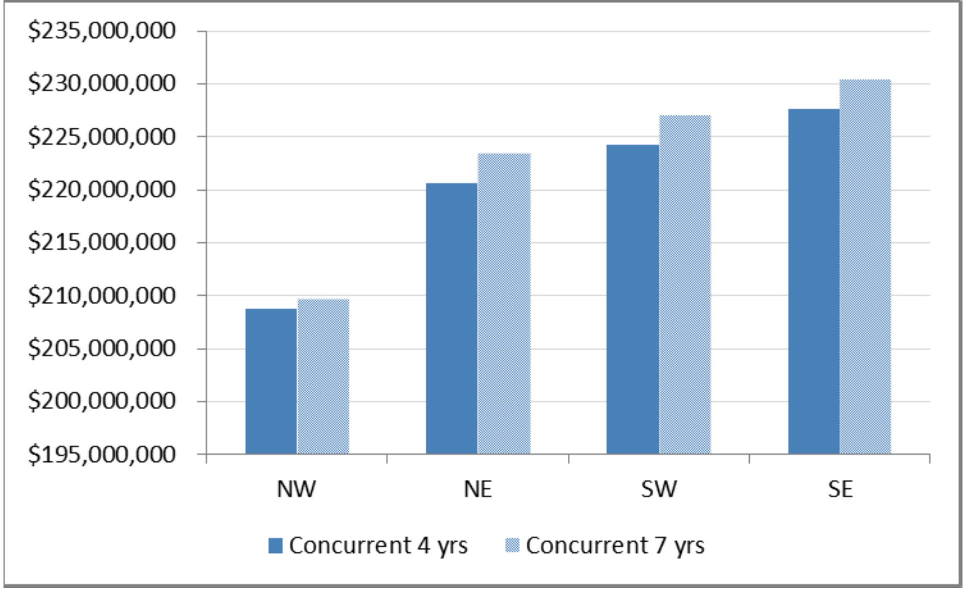
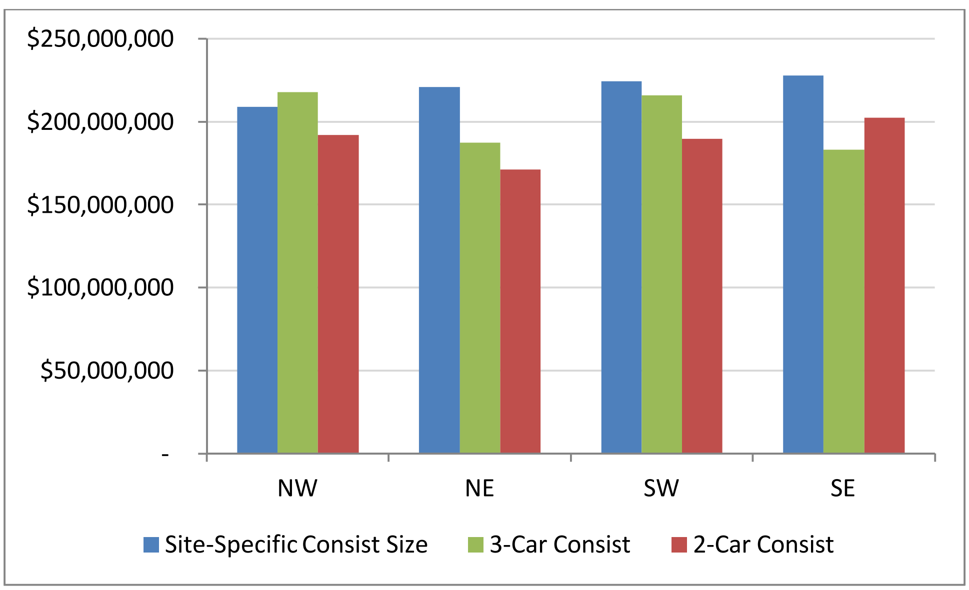


Figure 3. Total Cost as a Function of Campaign Duration.

Comparison between the Site Specific Consist Size Scenarios and 2-Car and 3-Car Consist Scenarios.

The total cost for the 4 year concurrent regional scenario is shown in Figure 4 for the site specific consist size and 2-car and 3-car consist cases in which either 2-car consist or 3-car consist was used for all sites. Using site-specific consist sizes resulted in higher total cost for all consolidated storage locations. The total cost was 8% to 22% higher compared to the 2-car consist cases. The 2-car consist cases result in the lowest total cost, except when the consolidated storage is located in SE region.



. **Figure 4. Total Cost as a Function of Consist Size for 4 Year Concurrent Regional Scenario.**

The Potential Range in the Total Cost of De-Inventorying

Among the scenarios considered in this analysis, the maximum total cost was calculated for the 7 year concurrent regional scenario with the site-specific consist sizes. The minimum total cost was calculated for the optimized scenario. The comparison between these two scenarios is shown in Figure 5. The difference between the lowest and highest total cost in the different consolidate storage locations ranges from 39% to 48%. The total cost in the 7 year optimized scenario and consolidated storage located in NE region ($115.6 Million) is 2 times lower than in the 7 year concurrent regional scenario and consolidated storage located in SE region ($230.4 Million). This range is similar to the range of $87 Million to $207 Million reported for a more generic analysis based on 31 different cases reported in Kalinina et al. (2013).

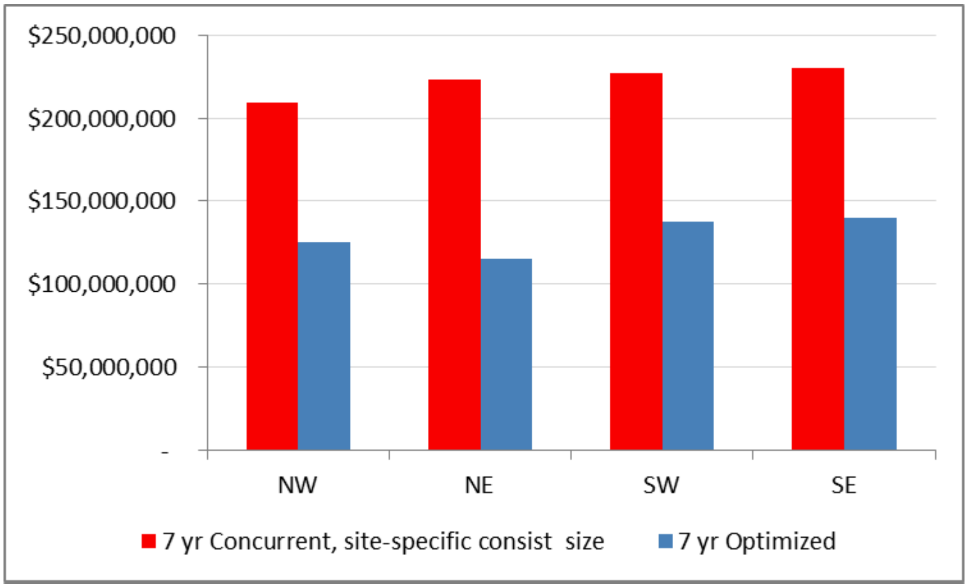


Figure 5. Comparison of the Scenarios with the Highest and Lowest Total Cost of De-Inventorying.

The total cost statistics are graphically presented in the box-and-whiskers plot in Figure 6. The NE location has the lowest median total cost, but the possible total cost range is the largest one. The SW location has the highest median total cost. The NW location has the smallest difference between the quartiles. The median total cost ranges from $187 Million to $216 Million. The total cost quartile range is from $171 Million to $228 Million.

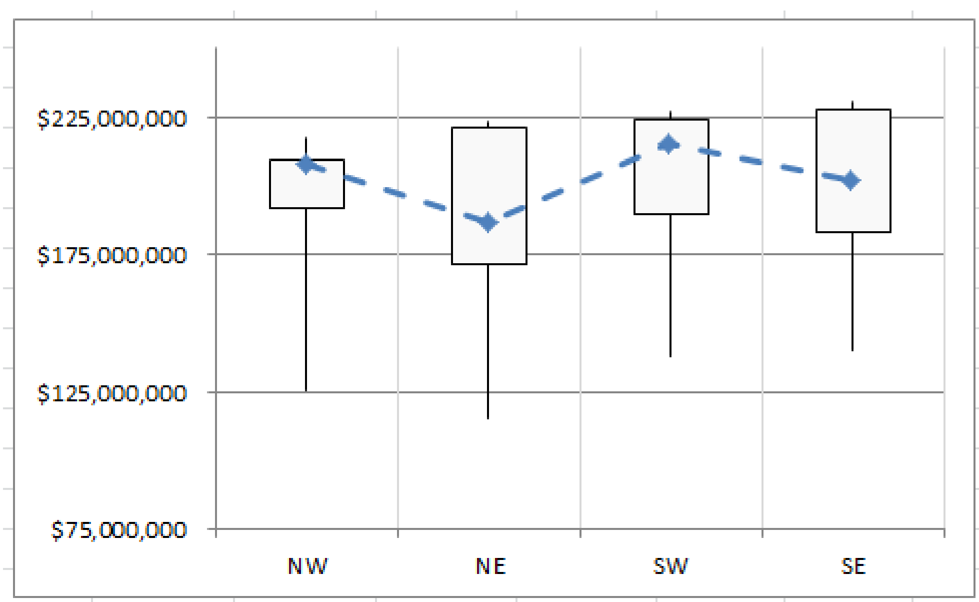
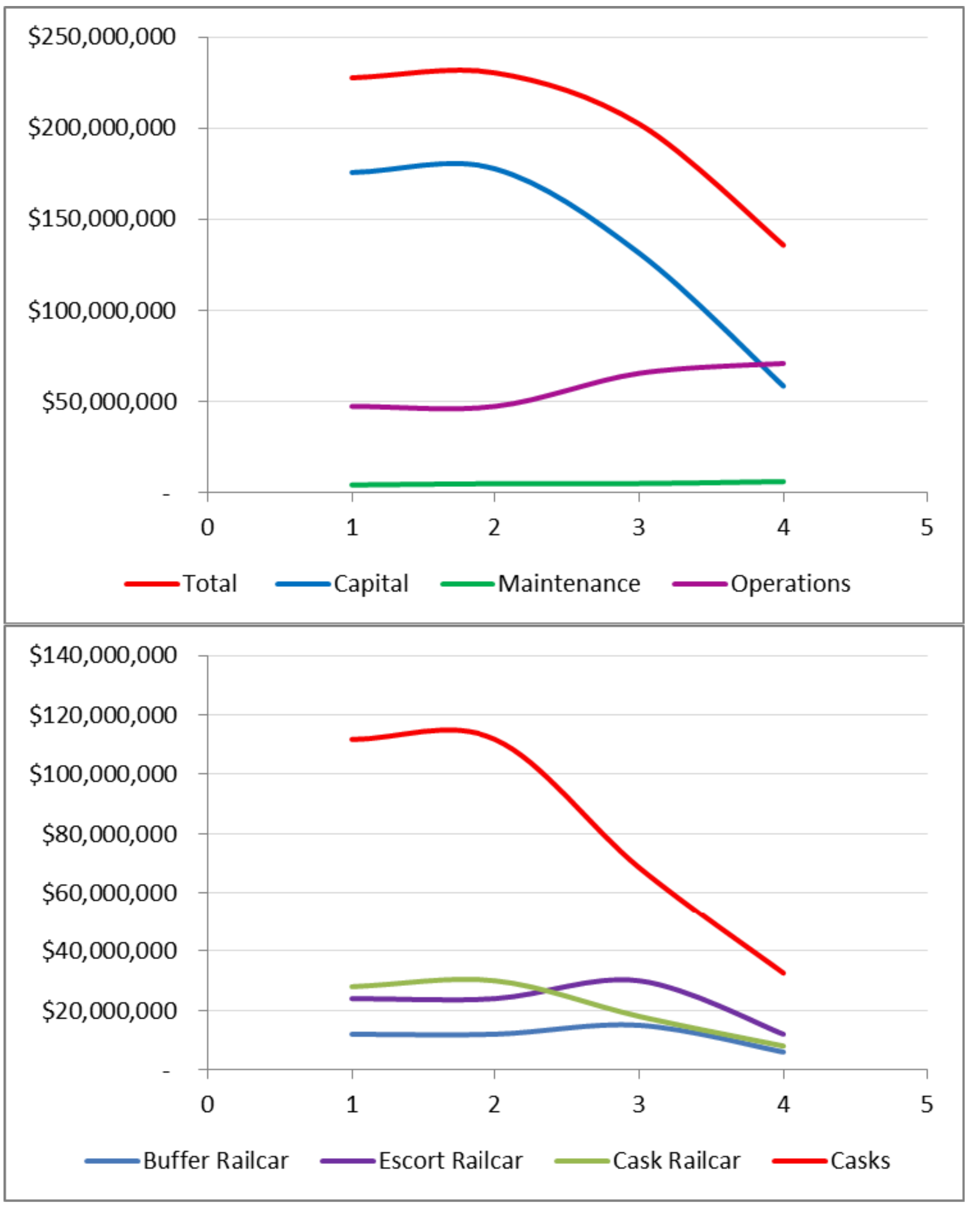


Figure 6. Scenario Statistics for the Different Consolidated Storage Locations.

ANALYSIS OF MAJOR FACTORS AFFECTING THE TOTAL COST

The cost constituents were analyzed to understand the differences in the total cost. These constituents are shown in two plots in Figure 7. The first plot indicates that the total cost is driven by the capital costs (cost of casks and vehicles). The capital cost curve follows the total cost curve. The maintenance costs are low compared to the total cost and similar in all the scenarios. The operational costs are lower for the scenarios with the site-specific consist sizes because fewer trips are required. However, increase in operational cost is small compared to the significant decrease in capital cost. Consequently, all the scenarios with the 2-car consist are noticeably lower in the total cost.

The plot shown at the bottom of Figure 7 indicates that the capital cost is driven by the cost of casks. The cask cost curve follows the capital cost curve shown in the top figure. The cost of vehicles is small compared to the cost of casks. The cost of vehicles is lower in the cases with the 2-car consist scenarios.



1 - 4 year concurrent scenario, site-specific consist; 2 - 7 year concurrent scenario, site-specific consist; 3 - 7 year concurrent scenario, 2-car consist; 4 – 7 year optimized scenario.

Figure 7. Cost Components for Different Scenarios.

Figure 8 shows the comparison between the number of vehicles and number of casks required in each scenario. The scenarios with the site-specific consist size require significantly larger number of casks. This result in the significantly higher capital cost compared to 2-car consist scenarios. The number of vehicles in the site-specific consist size scenarios is also larger, but the impacts on the capital cost are smaller. The optimized scenario with the lowest total cost is the one that requires the smallest number of vehicles and casks.

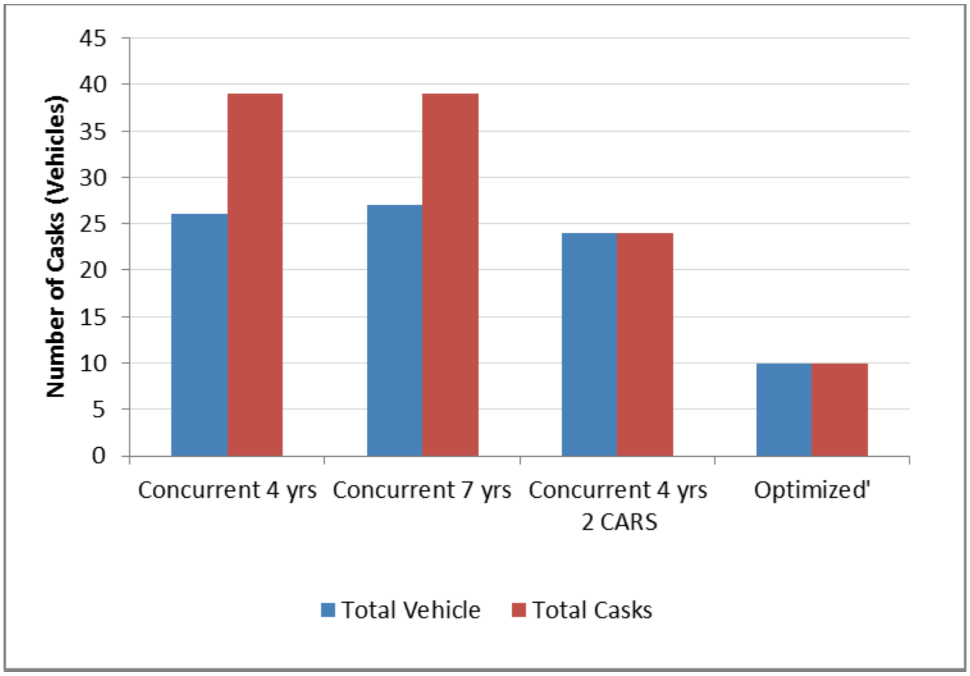
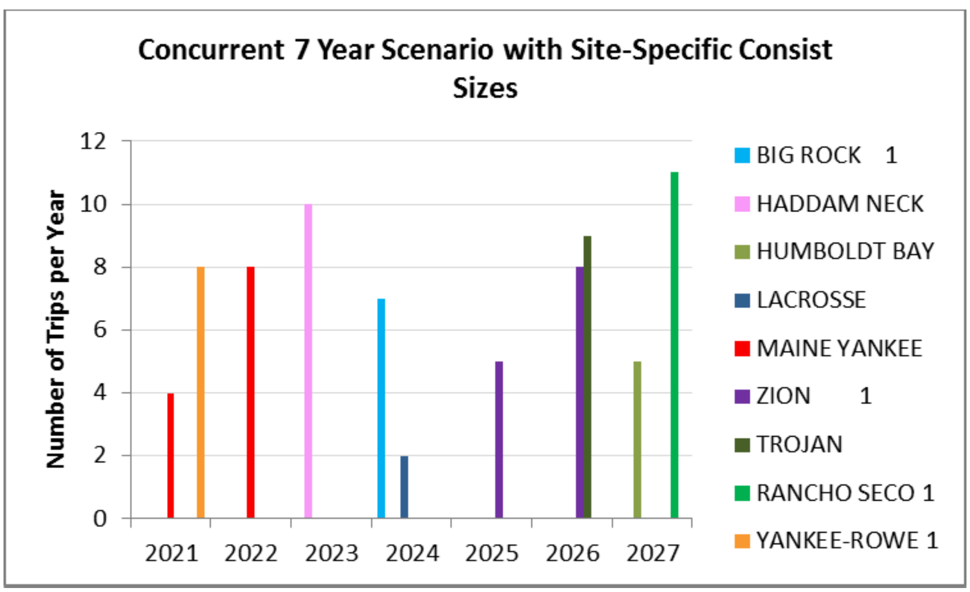
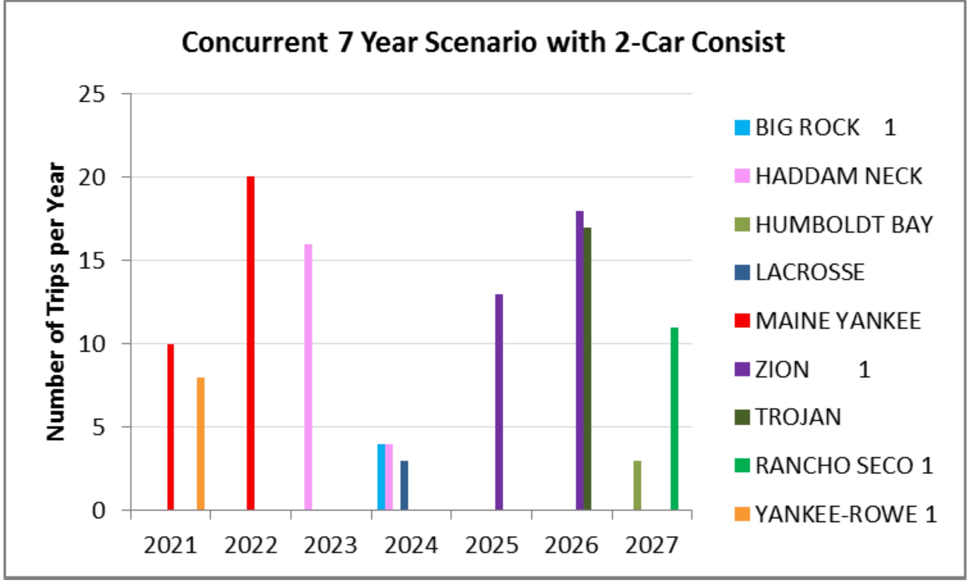


Figure 8. Acquisition Calculated for Different Scenarios.

Figure 9 compares the trip schedules for the 7 year concurrent scenarios with the site-specific consist size and 2-car consist. Because 5 and 4 car-consist are used at some sites in the first scenario, fewer trips (the total of 77 trips) are required to de-inventory the sites (Figure 9a). The second scenario (Figure 9b) requires significantly more trips (the total of 127 trips). However, because the operational cost (the cost of the trip) is small compared to the capital cost, the larger number of trips in the second scenario does not impact the total cost, which is noticeably lower.



(a)



(b)

Figure 9. Trip Schedules for Different Scenarios.

Figure 10 compares number of trips required to de-inventory different sites in concurrent regional scenarios with the site-specific consist and 2-car consist. More trips are required to de-inventory all the sires, except Humboldt Bay and Big Rock (one-car consist in the site-specific consist site scenario), in 2-car consist scenario.

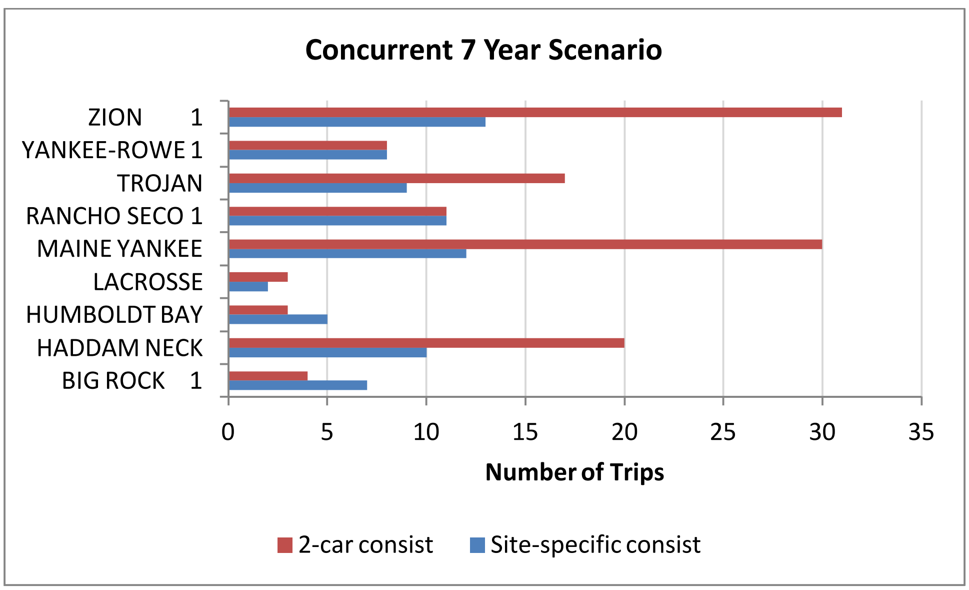


Figure 10. Number of Trips Required to De-Inventory Shutdown Sites.

CONCLUSIONS

The following conclusions can be made based on the results of this analysis.

- The sequence in which the different regions are de-inventorying has no impact on the total cost.
- The total cost is only slightly affected by the location of the consolidated storage.
- The consist size has the greatest impact on the total cost. The major differences in the total cost are between the scenarios with the site-specific consist size and 2-car consist scenarios.
- The major factor affecting the total cost is the cost of cask. The impacts from the other cost constituents are considerably smaller.
- Because the cost constituents other than the cost of the casks have small impact on the total cost, the variability in the parameters associated with these costs should not significantly affect the total cost.

- The lowest cost can be achieved by optimizing the number of casks and, to some extent, the number of vehicles required to realize the scenario. Consequently, it is important to have the most recent information associated with the cost of the casks.
- The obtained total cost range is from $116 Million to $230 Million. This range is consistent with the previous more general study of the de-inventorying shutdown sites (Kalinina et. al, 2013).

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