LOGISTICS CASE STUDY FOR SHIPPING USED NUCLEAR FUEL FROM SHUTDOWN REACTOR SITES

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ABSTRACT

The logistics case study presented in this paper considered multiple scenarios of shipping used nuclear fuel (UNF) from the shutdown reactor sites. The scenario variables included the campaign duration, fuel selection approach, consist size, and location of the consolidated storage and maintenance facilities. Thirty one simulations were performed using the Transportation Storage Logistics model. The major factors affecting scenario performance were identified and the recommendations concerning selecting appropriate strategies for transporting the UNF were 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 or facilities. The purpose of this hypothetical case study was to explore the logistics and costs associated with this option.

This case study is hypothetical because the locations of the consolidated storage facilities and the starting date of their operation were selected arbitrarily. The main goal of the study was to obtain a better understanding of what resources and time would be required to unload the shutdown sites.

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 most recent TSL version released in October 2012 was used to evaluate the different transportation scenarios considered in this analysis.

OBJECTIVES, METHOD AND PARAMETERS

Objectives

The purpose of this analysis is to assist in the process of selecting appropriate strategies for transporting the UNF from the shutdown sites. The major objectives of this analysis were:

- To consider possible scenarios of transportation of UNF from the shutdown sites to a potential consolidated storage facility;
- To identify major factors affecting scenario performance; and
- To rank (compare) the scenarios based on their performance.

Method

The modeling of the transportation scenarios was performed using the TOM component of TSL.

The major input into the transportation calculations is the pickup schedule. The pickup schedule defines the reactor sites from which the shipments will take place in a specified year during the transportation campaign and the number and types of casks to be shipped from each of these sites. TOM calculates the resources (casks and vehicles) required for meeting the defined pickup schedule and the timing of each trip (its transportation cycle).

The transportation cycle in TOM begins and ends at the fleet maintenance facility. The following activities are simulated:

1. traveling to the pickup site,
2. loading the fuel into casks and onto the transportation asset,
3. traveling to the storage facility,
4. unloading the cask, unloading the fuel, and loading the empty cask onto the transportation asset,
5. traveling to the cask maintenance facility,
6. performing cask maintenance,
7. traveling to the fleet maintenance facility, and
8. performing fleet maintenance

The cask maintenance facility can be co-located with the fleet maintenance facility. The maintenance facilities can be co-located with the storage facility. In these cases, the travel between the corresponding facilities is eliminated.

Another important input parameter is the maximum default consist size, i.e., the maximum number of cask to be shipped at a given time. This size is applied to all the sites, unless the site-specific option is used. In the latter case, a site-specific maximum consist size can be specified for any site. This information 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 call to a 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 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 main assumption in cost calculations is related to the cost of the transportation asset operations (a dedicated train shipment by a mainline carrier). The calculated mainline rail costs in TOM are an approximation of what the actual charges would be. The costs are a function of the weight of the casks, the number of cask cars, and the distance travelled.

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.

The calculation method is based on the following assumptions.

- The transportation networks as they are now will be usable at such time as UNF is to be moved.
- There can only be one consist loading at the reactor at a time.
- The unloading capability at the consolidated storage facilities is unlimited.

These assumptions should not have a significant impact on evaluating different transportation scenarios. However, they can affect the scheduling of the actual operations.

Parameters

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.

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.

The major input parameters into this analysis are: pickup schedule, consist size, and consolidated storage and maintenance facilities locations.

The pickup schedule is a function of the campaign duration and the fuel selection approach. The following campaign durations were considered: 1, 2, 3, 4, 5, 6, and 8 years. In all cases it was assumed that a hypothetical consolidated storage facility starts its operations in 2014.

Three fuel selection approaches were considered. In the first approach, the fuel selection was performed by CALVIN. CALVIN selects fuel by using older fuel first rule. In the second, “sequential” approach, the fuel was selected to allow for sequential unloading of the shutdown sites, when possible. In the third, “parallel” approach, the attempt was made to unload a few sites in parallel, when possible.

As a result, nine different schedules were developed. Not all of the combinations of campaign duration and fuel selection approach were considered, as described below.

Three maximum default consist sizes were considered: one-car consist, two-car consist, and three-car consist. In two scenarios site-specific consist sizes were used. In the first scenario, the 5-car consist was defined for Maine Yankee and a 3-car consist for all the other sites. In the second scenario, a 2-car consist was defined for Big Rock Point, La Crosse, and Humboldt Bay and a 3-car consist for all of the other sites.

Four locations for the hypothetical consolidated storage facilities were considered: Southeastern USA, Southwestern USA, Northwestern USA, and Northeastern USA. In most cases, the maintenance facilities were co-located with the consolidated storage facilities. A few scenarios considered the maintenance facilities in

Southwestern USA, Northwestern USA, and Northeastern USA, while the consolidated storage facility was in Southeastern USA.

Finally, the initial conditions (Table 1) were modified to evaluate the benefit of using NAC-MAGNATRAN instead of NAC-STC casks at Haddam Neck, Yankee Rowe, and La Crosse sites.

Thirty-one scenarios were considered (Table 2). These scenarios represent only a subset of all of the possible combinations of the different parameters and initial conditions.

Table 1. Used Nuclear Fuel Inventory Stored at Shutdown Sites

Site	Fuel Type	Number of Assemblies in Storage	Type of Storage Canister	Canister Capacity	Number of Canisters	Type of Transportation Overpack
Big Rock Point	BWR	441	W150	64	8	TS-125
Haddam Neck	PWR	1019	MPC-26	26	40	NAC-STC
Maine Yankee	PWR	1434	UMS-24	24	60	NAC-UMS
Yankee Rowe	PWR	533	MPC-36	36	15	NAC-STC
Rancho Seco	PWR	493	24PT	24	21	MP187
Trojan	PWR	780	MPC-24E/EF	24	34	HI-STAR 100
Humboldt Bay	BWR	390	MPC-80	80	5	HI-STAR 100
La Crosse	BWR	333	MPC-LACBWR	68	5	NAC-STC
Zion 1 and 2	PWR	2226	TSC-37	37	61	NAC-MAGNATRAN

NOTE: These data are from (Leduc, 2012)

Table 2. Transportation Scenario Parameters

NN	Scenario NN	Campaign duration, years	Schedule	Consist Size	Consolidated Storage	Maintenance Facility	MAGNATRAN
1	1	6	Calvin	1	SE	SE	
2	801	6	Calvin	2	SE	SE	
3	802	6	Calvin	3	SE	SE	
4	803	6	Calvin	3 and 5	SE	SE	
5	804	6	Calvin	3 and 2	SE	SE	
6	810	6	Sequential	2	SE	SE	
7	811	6	Sequential	3	SE	SE	
8	812	6	Parallel	2	SE	SE	
9	813	6	Parallel	3	SE	SE	
10	814	5	Parallel	2	SE	SE	
11	815	5	Parallel	3	SE	SE	
12	816	4	Parallel	2	SE	SE	
13	817	4	Parallel	3	SE	SE	
14	818	3	Parallel	2	SE	SE	
15	819	3	Parallel	3	SE	SE	
16	820	2	Parallel	2	SE	SE	
17	821	2	Parallel	3	SE	SE	
18	822	1	Parallel	2	SE	SE	
19	823	1	Parallel	3	SE	SE	
20	824	4	Parallel	2	SE	SE	Yes
21	825	6	Parallel	2	SE	SE	Yes
22	826	4	Parallel	2	SE	SW	
23	827	4	Parallel	2	SE	NW	
24	828	4	Parallel	2	NW	NW	
25	829	4	Parallel	2	SW	SW	
26	831	4	Parallel	2	NE	NE	
27	833	4	Parallel	2	SE	NE	
28	834	8	Parallel	2	SE	SE	
29	835	8	Parallel	3	SE	SE	
30	836	8	Parallel	1	SE	SE	
31	837	8	Parallel	2	SE	SE	Yes

NOTE: SE – Southeastern USA, SW – Southwestern USA, NE – Northeastern USA, NW – Northwestern USA, “Yes” in MAGNATRAN column identifies scenario in which MAGNATRAN casks were used instead of NAC-STC.

Each scenario has an ID under which it was saved in TSL's database and which designates a specific combination of parameters.

TSL was executed for each scenario. The output of each simulation included the detailed schedule of all the transportation activities for the duration of campaign, trip report, cost report, and acquisition report.

RESULTS

The results of the transportation simulations were analyzed to identify the effects of the campaign durations, fuel selection approach, consist size, location of the consolidated storage and maintenance facilities, and use of NAC-MAGNATRAN casks instead of NAC-STC casks.

Campaign Duration

The transportation costs and acquisition (the number of casks and vehicles) as a function of the campaign duration are shown in Figure 1 for 2-car consist and 3-car consist scenarios. All of the scenarios consider parallel schedule, consolidated storage in Southeastern USA, and maintenance facility co-located with consolidated storage.

The following conclusions can be made based on the results shown in Figure 1.

- The total cost rapidly decreases from a 1-year campaign to a 4-year campaign and then only slightly decreases from a 4-year campaign to an 8-year campaign. The high total cost during the short duration campaigns is related to the high capital costs.
- The operational and maintenance costs do not significantly change with the campaign duration.
- The maintenance cost is only a small fraction of the total cost.
- For the longer campaigns, the capital and operational costs are comparable for the 2-car consist scenarios. For the 3-car consist scenario, the capital costs are higher than the operational costs (more casks are required for the 3-car consist).
- The total costs in the 3-car consist scenarios are 11%-13% higher than in the 2-car consist scenarios. The 2-car consist scenarios have higher operational costs (more trips per year), but lower capital costs (fewer casks are required).

Figure 2 compares the total transportation costs in the 2-car and 3-car consist scenarios to the dry utility costs. The dry utility costs are the costs to maintain dry storage facilities at the remaining shutdown sites. These dry costs are calculated for the duration of the campaign starting from the first campaign year. The annual cost of 6 million dollars per site is the current value in CALVIN database and this value was used in the example in Figure 2. The dry storage costs increase nearly linearly as a function of the campaign duration. Consequently, unloading of the shutdown sites in 3-5 years seems to be the optimal schedule with regard to keeping low transportation costs and dry storage costs.

Consist Size

The transportation costs, number of trips per year, and acquisition as a function of consist size are shown in Figure 3 for 6-year and 8-year campaigns. All of the scenarios consider parallel schedule, consolidated storage in Southeastern USA, and a maintenance facility co-located with consolidated storage. The scenarios with the site-specific consist (scenarios 803 and 804 in Table 2) were assigned non-integer numbers in between the default consist and site-specific consist to display the results of these scenarios in a graphical format.

The capital costs increase nearly linearly with the consist size because more casks and vehicles are required for larger consists. The operational costs decrease non-linearly with the consist size because fewer trips are required. As a result, the best scenarios (measured by the lowest total cost) are the ones with the 2-car consists. The consist size does not significantly affect the maintenance costs. These costs represent a small fraction of the total cost.

The number of trips decreases with the increasing consist size. However, the average trip cost increases with the increasing consist size. The major contributor to the average trip cost is the mainline rail cost, which is a function of the weight of the casks, the number of cask cars, and the distance travelled. This example demonstrates that the costs related to the cask cars in the case of large consist overcome the benefit of traveling smaller distances.

Fuel Selection Approach

Figure 4 compares the costs and acquisitions for the sequential and parallel approaches. The scenarios shown in Figure 4 are for 2-car and 3-car consists for the case of a 6-year campaign. The consolidated storage facility is located in Southeastern USA and the maintenance facilities are co-located with the consolidated storage.

The total cost is significantly higher in the sequential approach because more casks are required. As a result, the capital costs increase, which in turn increases the total cost. The operational and maintenance costs are very similar in both approaches.

The greater the consist size, the larger the impacts of sequential unloading on the total cost as is evident from Figure 4.

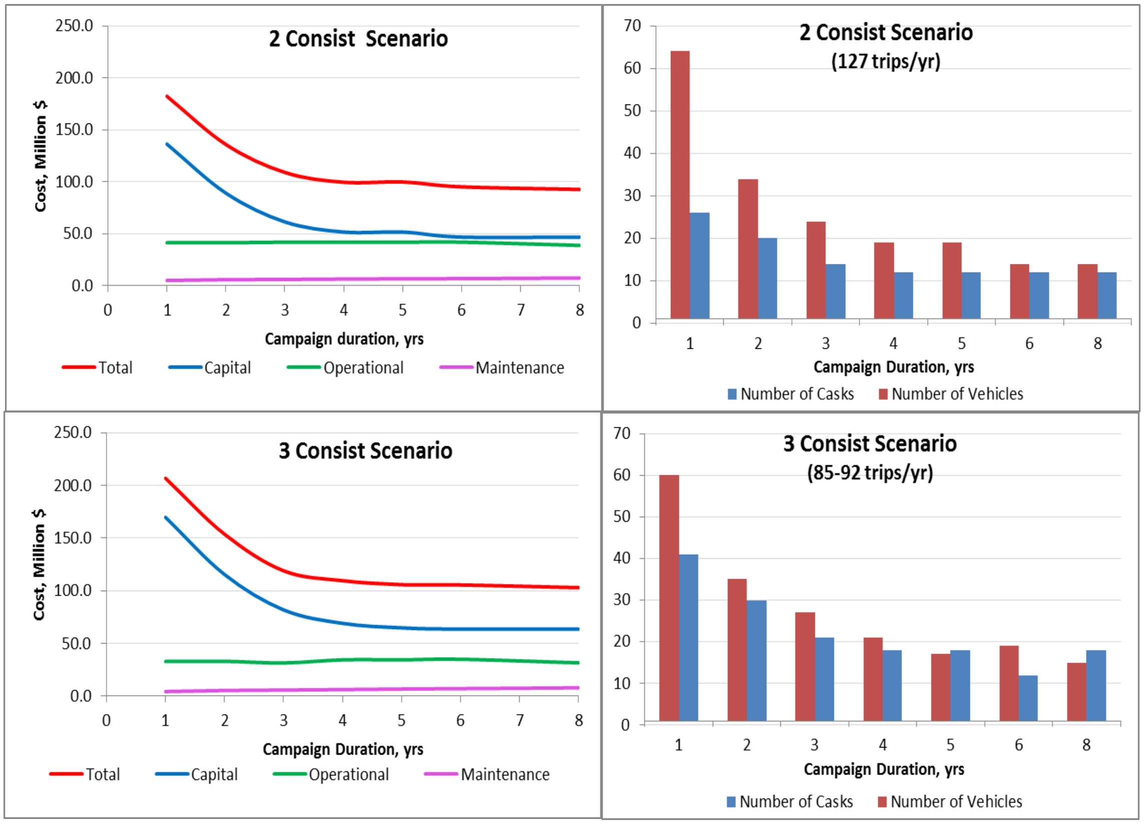

Figure 1. Cost and Acquisition as a Function of Campaign Duration for 2-Car Consist and 3-Car Consist Scenarios.

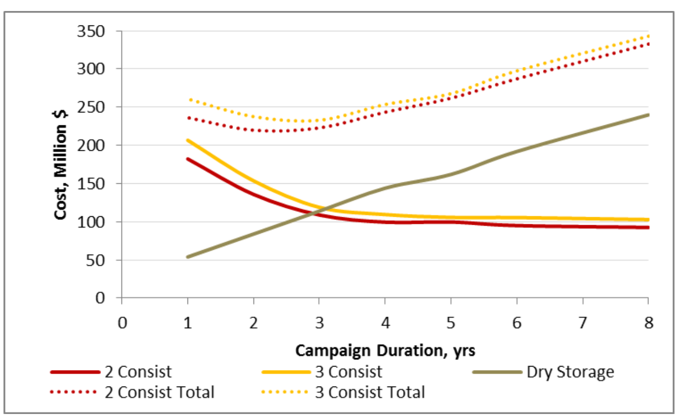

Figure 2. Total Transportation Costs for 2-Car and 3-Car Consist Scenarios Compared to Dry Storage Costs.

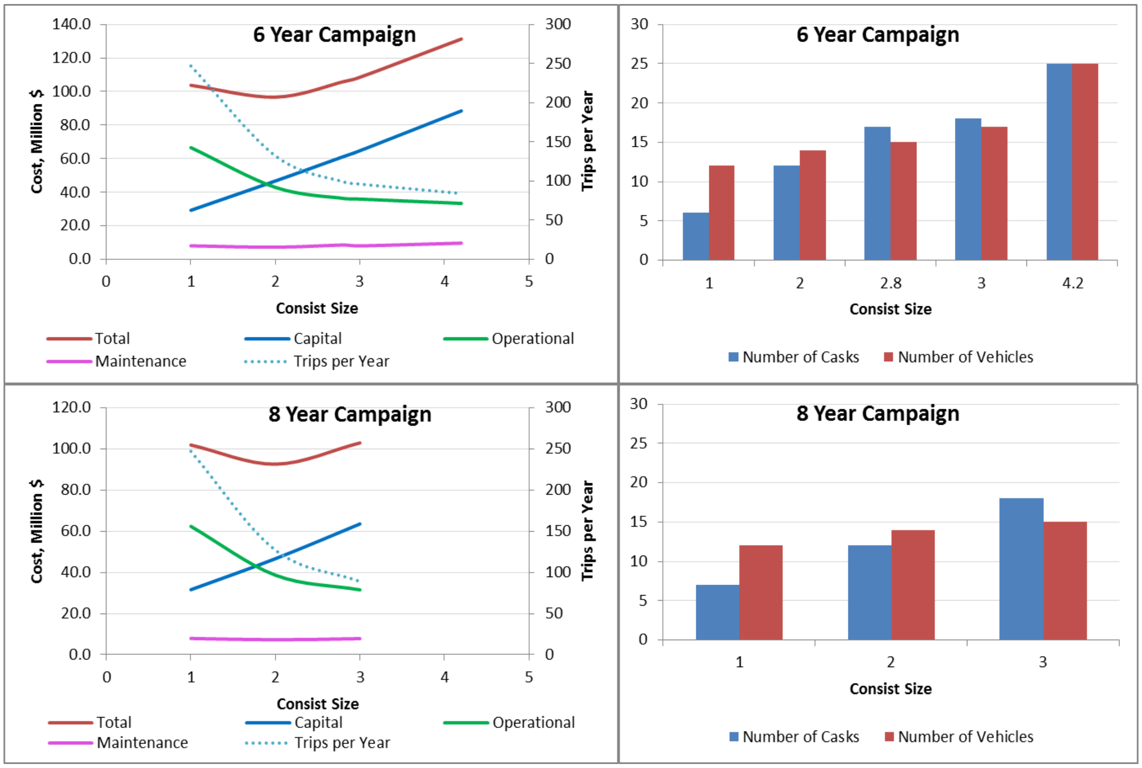

Figure 3. Cost and Acquisition as a Function of Consist Size for 6- and 8-Year Campaigns.

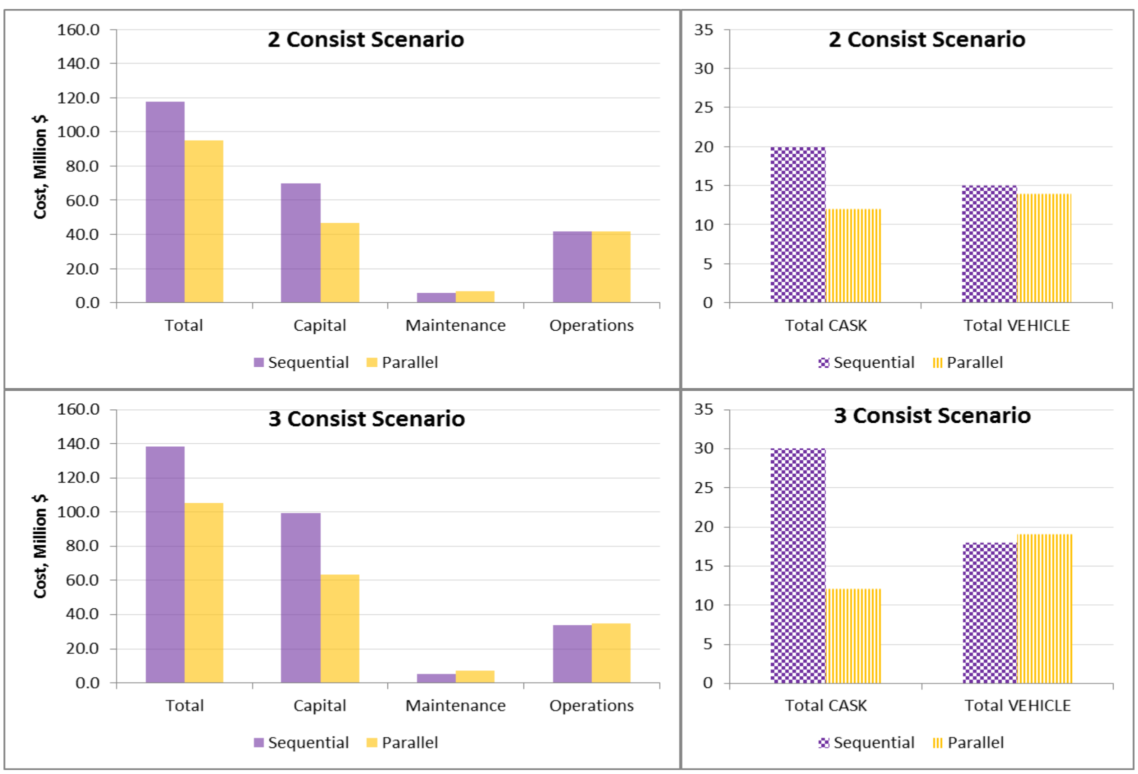

Figure 4. Cost and Acquisition as a Function of Fuel Selection Approach for 6-Year Campaign.

Use of MAGNATRAN Casks

Figure 5 compares the scenarios in which site-specific NAC-STC casks were used at Haddam Neck, Yankee Rowe, and La Crosse sites to the scenarios in which NAC-STC casks at these three sites were replaced with NAC-MAGNATRAN casks. All scenarios considered the parallel fuel selection approach, 2-car consist size, consolidated storage in Southeastern USA and maintenance facilities co-located with the consolidated storage facility.

Using the same cask types (NAC-MAGNATRAN) at multiple sites has benefits only for the long duration (greater than 6 years) campaigns. In this case, fewer casks are required in the scenarios in which NAC-MAGNATRAN casks are used instead of NAC-STC casks.

If the campaign is short, using the same casks type results in higher total costs. The number of casks required to transport the fuel remain the same in both cases. In the first case (site-specific casks), all the casks are acquired in the first year of campaign. In the second case (NAC-MAGNATRAN instead of NAC-STC) some of NAC-MAGNATRAN casks are acquired later in the campaign at the higher price.

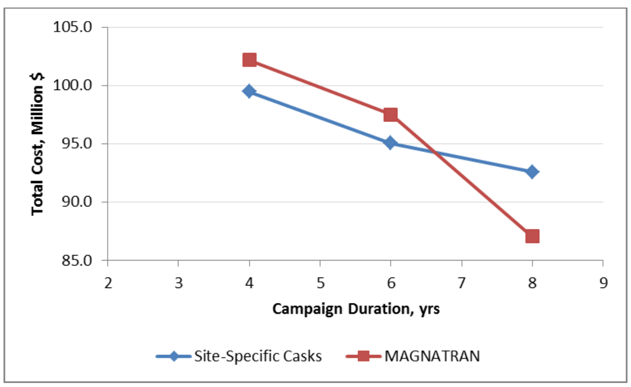

Figure 5. Total Cost for the Different Transportation Cask Scenarios as a Function of Campaign Duration.

Consolidated Storage and Maintenance Facility Locations

The effects of consolidated storage and maintenance facility locations are shown in Figure 6 for scenarios with a 2-car consist size, parallel fuel selection approach, and 4-year campaign.

Locating the consolidated storage facility farther from the majority of the shutdown sites results in significant (43%) total cost increase (consolidated storage facility in Northwestern USA). The increase in total cost is due to the increase in operational costs. The capital costs increase slightly because more casks are needed due to greater turnaround times (greater distances traveled). The effects on the maintenance costs are very small.

Locating maintenance facilities away from the consolidated storage facility results in significant (35%) total cost increase (as in the case of consolidated storage in Southeastern USA and maintenance facilities in Northwestern USA). The increase in total cost is mainly due to the increase in operational costs. However, the capital costs increase as well because more casks are needed due to additional time required for sending casks and vehicles to the maintenance facilities for maintenance. The effects on the maintenance costs are very small.

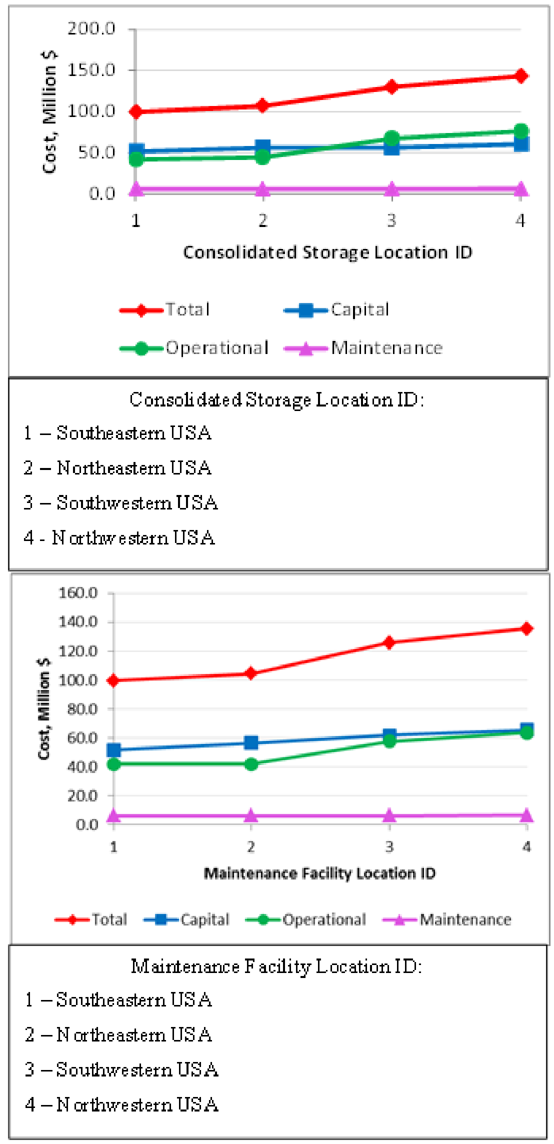

Figure 6. Cost Components for Scenarios with Different Locations of Maintenance Facility and Consolidated Storage Facility.

In both cases, the increase in the operational costs is mainly due to the increase in mainline rail costs, which is a function of distance traveled.

Scenario Ranking Based on Their Performance

The scenarios considered in this analysis (Table 2) were ranked based on their differences (in percent) from the base case with regard to the total costs, capital costs, and operational costs. The maintenance costs were not considered because their contribution is very small. Scenario 816 (sequential schedule, 4-year campaign, 2-car consist, consolidated storage facility in Southeastern USA, co-located maintenance facilities) was selected as the base case because it is close to optimal with regard to the total cost and campaign duration. The results are shown in Figures 7 through 9.

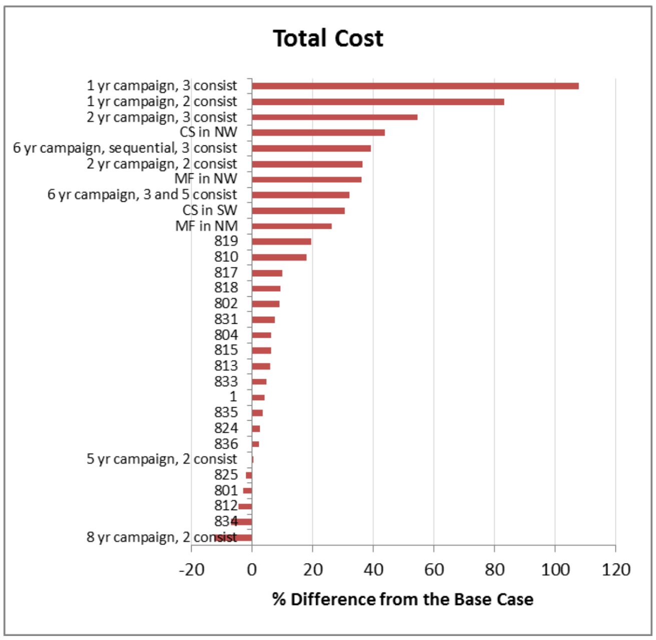

Figure 7. Differences in Total Costs between the Base Case and the Other Scenarios.

The major factor affecting the capital costs is the campaign duration. The next two important factors are the fuel selection approach and the consist size. The short campaign, sequential schedule, and large consist scenarios result in significantly (up to 3.9 times) higher capital costs than in the base case. The impact would be even higher in the case when these three factors are combined.

The total costs are generally affected by the same factors as the capital costs except the location of the consolidated storage facility and maintenance facilities becomes an important factor as well.

The major factor affecting the operational costs is the location of the consolidated storage and maintenance facilities. The next important factor is the consist size. The consolidated storage (and maintenance facility) located in Northwestern USA results in significantly (up to 1.9 times) higher operational costs than in the base

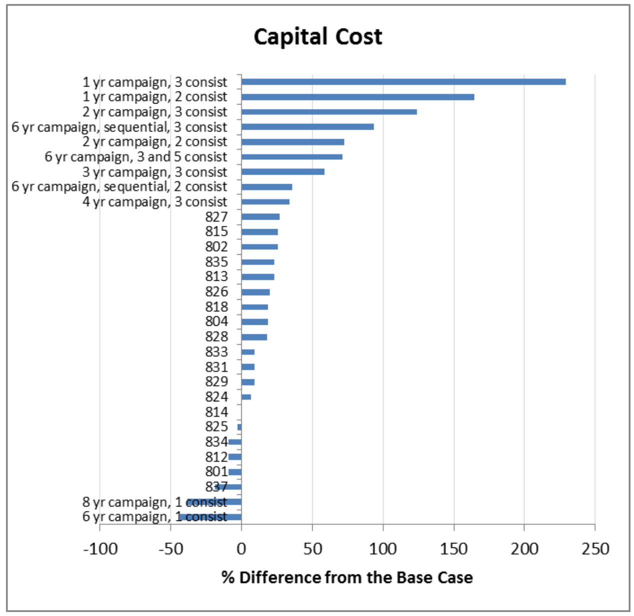

Figure 8. Differences in Capital Costs between the Base Case and the Other Scenarios.

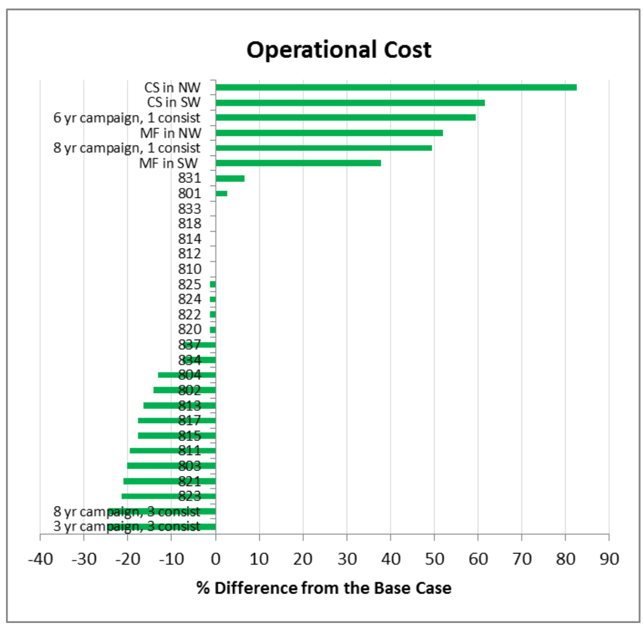

Figure 9. Differences in Operational Costs between the Base Case and the Other Scenarios.

case. The impact would be even higher in the case when these two factors are combined.

CONCLUSIONS

The total transportation cost related to unloading the shutdown sites is a function of the campaign duration, fuel selection approach, consist size, and location of the consolidated storage and maintenance facilities.

The highest costs were calculated for the scenarios with short duration campaign, sequential schedule, large consist size, consolidated storage located far from the majority of the shutdown sites, and maintenance facilities not co-located with the consolidated storage.

The major contributors to the total cost are capital cost and operational cost. Depending on the scenario parameters, the capital cost may be greater than, comparable to, or smaller than operational cost. Generally, the factors that minimize capital costs (small consist), maximize the operational costs and vice versa.

The best scenario in terms of cost for removing stranded fuel form the nine sites based on the results of this analysis would be to:

- locate the consolidated storage facilities close to the majority of the shutdown sites and
- unload the sites in parallel over 4 or 5 years
- use 2-car consist for transport, and
- use the transportation casks currently licensed for each site.

Longer campaigns would be slightly less expensive, but would result in higher dry storage maintenance costs.

The result of this analysis should be used as a general guidance. There are many specific details that were not considered in this analysis and these details may affect the selection of the best strategy in unloading the shutdown sites.

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