Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

# Erie Pier Re-Use Facility Phase II: An Optimized Cost-Effective Strategy for Increased Transport and Handling of Dredged Materials

## Final Report


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# *Executive Summary*

Growing constraints on options for placing dredged materials at the Erie Pier Confined Disposal Facility (CDF) urged action on a plan to recycle the material at the pier. Potential recycle operations and customers to utilize the dredged materials were studied in the Erie Pier Phase I project in 2008. Of two products included in the dredged materials (designated “coarse” and “fines”), the fines cause the most concern for recycling because of this product’s relatively limited usage. Given the Duluth-Superior Metropolitan Interstate Council’s Management Plan goal to prolong the life of Erie Pier indefinitely, Phase I of this research studied the possible depletion of dredged materials from Erie Pier, most of which are fines, accumulated at the pier. Phase II research supports this plan to reconfigure the CDF into a re-use facility at least cost, and to develop an optimized transportation plan to move the dredged materials from the pier to several potential customers.

Transportation modes evaluated include rail plus truck, truck only, and the RailMate™ system. Potential customers include four large-scale long-term projects and seven short-term recurring projects that are able to utilize the fines material. Long term projects include soil enrichment for the Duluth Wetlands Habitat at 21st Ave. W., and construction fill at the CN Railroad Ore Docks, Hibbard Power Plant, and at Sky Harbor Airport. Short term recurring customers include Keetac (Keewatin Taconite), UTAC (United Taconite), Wisconsin Waste Management in Superior, Waste Management in Canyon and Elk River, and farmers in the Wrenshall and Floodwood areas. A series of scenarios were created to help Erie Pier decide which customers to serve and what transportation mode(s) to use under different situations. For each scenario, an optimal year-by-year plan was developed to specify how much and by what mode the dredged materials should be shipped to each chosen customer in each year. The overall objective in all the scenarios analyzed is to achieve the least present value of total transportation cost.

A pre-screening analysis for the three transportation modes first eliminated the rail plus truck option since it provides an obviously inferior solution to the RailMate option. As compared to RailMate, the rail plus truck option involves the following: 1) Higher $/ton unit transportation cost on rail and road. 2) Three times RailMate’s loading and unloading cost. 3) Hidden costs of dealing with truck companies and rail carriers for individual contracts and taking care of the inter-modal scheduling. 4) High cost (6-18 million dollars) and time delay (up to five years) when applying for a transfer yard permit.

The RailMate system is an innovative way of transporting commodities by combining the advantages of truck and rail transportation. American Surface Lines, LLC, has designed bogies that can easily convert an end-dump trailer into a rail car in 8 minutes. It eliminates the high costs involved in the loading and unloading between trucks and rail cars of inter-modal transportation. Since only 132 feet of flat surface is needed to transfer a trailer, the conversion can be done not only at designated rail stations but also at rail track locations that are closer to customers. With this innovative solution, American Surface Lines, LLC is willing to haul dredged materials at a unit cost of $17/ton to customers located within 30 miles of the rail track, regardless of the total delivery distance.

Two trucking companies were surveyed and price quotes were obtained. Lakehead Trucking offers one truck option with a cost of $2.25/cubic yard mile. Each truck load is 18 cubic yards per load. Quotes from Udeen trucking is $90/hour to use their quad trucks with a capacity of 14 cubic yards per load and $100/hour to use the end dump truck with a capacity of 20 cubic yard per load.

Since the removal of fines material turned out to be more of a problem than the removal of coarse material, analyses focused on the distribution of the fines materials to possible customers. It is estimated that 1,250,000 cubic yards of fines are currently stored at the pier, and an additional 50,000 cubic yards could be added annually. It is also assumed that there are three bulldozers and three loaders available at the pier to perform the loading task. Due to supply and capacity issues, the maximum amount of materials that can be removed from the pier is assumed to be 100,000 cubic yards per year.

Four major steps were involved in the model building and scenario analysis stage as follows:

**Step 1:** For each customer, the optimal number of trucks to use each day, and the daily schedule for pick-up and delivery were determined. Individual spreadsheets were created for each customer in order to use each of the three different trucking options obtained from the two truck companies. (This was later linked to the optimization model at the second step.) Factors considered here include the loading capability at Erie Pier and the distances between the trucking company, the pier, and the customer.

**Step 2:** An optimization model using integer linear programming was built to help decide which customers Erie Pier should serve, and in which transportation mode the dredged materials should be delivered. Note that with the prescreening analysis performed earlier, only the truck option and the RailMate option were included in the model. A constraint was set in the model to ensure that only one transportation mode could be selected for each chosen customer. This helped reduce the contracts that Erie Pier would need to deal with when delivering fines to a customer.

**Step 3:** Since customers with recurring short-term projects did not specify how long they would like to receive the fines, the number of recurring years for each short-term customer was treated as an additional variable. To determine the optimal number of years that those projects should recur, the model built in step 2 was run hundreds of times in order to identify the least cost scenario.

**Step 4:** With the customers, transportation mode, and the recurring years for short-term projects determined, a year-by-year delivery plan for the dredged materials at Erie Pier was developed. This was achieved by a second-stage integer linear programming model. The objective was to minimize the total present value of the transportation cost while meeting customers' needs. A 4% inflation plus interest rate was assumed in the calculation.

To create a series of scenarios as back up plans in case certain assumptions employed in the model become invalid, steps 2 to 4 were repeated by resolving models with certain constraints added or relaxed.

The overall optimal solution suggests the use of RailMate to serve two long-term customers (construction fill at the CN Railroad Ore Dock and the Hibbard Power Plant), and two short-term recurring customers (land fill for Waste Management at Canyon and mine reclamation at UTAC). The associated costs are shown in Table I.1.

**Table I. 1 Overall Optimal Solution**

| Project Selected | Total Fines Removed (Cubic Yards) | Transportation Option | Transportation Costs |
|---|---|---|---|
| Waste Management (Canyon, MN) | 106,035 (recur 5 years) | RailMate | $176,452.84 |
| UTAC | 44,365 (recur 5 years) | RailMate | $73,827 .8 |
| CN Railroad Ore Dock | 950,000 | RailMate | $1,497,690 |
| Hibbard Power Plant | 1,000,000 | RailMate | $1,664,100 |
| Total Materials Used: 2,050,400 cubic yards | | | |
| Total Transportation Costs: $3,412,070.64 | | | |
| Total Loading and Equipment Costs: $11,998,358.72 | | | |
| **Total Project Costs: $15,410,429.36** | | | |

It is expected that 90% of the fines accumulated at the pier plus the annual additions will be depleted in 21 years. During this period, Erie Pier could serve as a reuse facility since the dredged materials would be processed and recycled to serve customers' needs. The year-by-year plan for the overall optimal solution suggests serving Hibbard Power Plant in years 1–12 and the CN Railroad Ore Dock in years 12–21. The amount of fines to be delivered to these two customers in each designated year can be seen in Table I.2. The year-by-year plan for this optimal solution also suggests that Erie Pier supply UTAC in the first five years to satisfy its annual demand of 8,873 cubic yards, and serve Waste Management at Canyon, MN in years 1–4 and 21 to meet its annual demand of 21,207 cubic yards.

**Table I. 2 Year-by-Year Plan for the Overall Optimal Solution**

| Project Selected | Years Selected | Cubic Yards Per Year |
|---|---|---|
| Waste Management (Canyon, MN) | 1 – 4, 21 | 21,207 |
| UTAC | 1 – 5 | 8,873 |
| CN Railroad Ore Dock | 12 - 21 | Year 12: 70,807<br>Years 13-20: 100,000<br>Year 21: 29,193 |
| Hibbard Power Plant | 1 – 12 | Years 1 – 4: 69,920<br>Year 5: 91,127<br>Years 6 – 11: 100,000<br>Year 12: 29,293 |
| Total Transportation Costs (including 4% inflation & interest): $5,344,706.59 | | |
| **Total Project Costs: $17,343,065.31** | | |

Several other scenarios were analyzed. In the truck-only scenario, the total transportation cost obtained from the optimal case is almost three fold. Environmentally, the truck option also raises important concerns about fuel emissions and traffic congestion on the road. In conclusion, among the three transportation modes being considered, RailMate stands out as the most cost effective and environmentally friendly option. As shown in Table I.2, the total loading and equipment costs were a significant part of the total project cost. This is associated with the high labor cost of loading the materials to the RailMate trailers, and the purchase of four new bulldozers and four loaders during the project life. Since Erie Pier is located close to a rail track, it is suggested that Erie Pier consider installing an automatic loading system such as a belt conveyor to transfer the dredged materials directly to RailMate trailers on the rail track, for long term benefits.

# 1. Introduction

## 1.1 Summary of Findings of Phase I

Although many ports face Confined Disposal Facility (CDF) capacity pressure, the Duluth-Superior Port has an urgent need to implement an alternative plan to the status quo for dredged materials. An initial Erie Pier project (Phase I) was completed to determine cost accounting and capital budgeting for a proposed Process Re-use Facility (PRF). Previous work, such as the US Army Corps of Engineers' Dredged Material Management Plan (DMMP) for the Duluth-Superior Harbor, April 1999, and the Duluth-Superior Metropolitan Interstate Council's Erie Pier Management Plan, June 2007, identified possible re-uses for dredged material. The potential customer list included mineland reclamation projects, construction sites, road construction, daily landfill cover, topsoil creation and enhancement, habitat restoration, and habitat creation.

Phase I found that for budgetary purposes, it could be appropriate to assume that yearly, 48,000 yards of coarse material (sand) and 50,000 yards of fine material (clay and other material) are available from Erie Pier. In addition, Erie Pier contains a removable total accumulation of 1,250,000 yards of fine material. These and other assumptions were estimated with the help of the Duluth-Superior Harbor Technical Advisory Committee's Dredging Sub-committee.

## 1.2 Phase I Data Collection

A wide range of possible customers were considered, and feasible customers were determined from a wider group of potential customers, through phone interviews, and data collection on landed cost, competition, and supply chain for various markets. Of special interest were long-term projects such as the 21st Avenue West Habitat Restoration. Potential customers were drawn from the industry sectors of Compost, Topsoil, Construction, Ground Cover, Soil Enrichment, Land Fill, and Mine Reclamation.

Discussion in Phase I covered aspects of product markets for feasible partners and the demand market for Erie Pier fines. Given that transportation is the largest cost for any of the identified applications of dredged material from Erie Pier, estimations were offered to compare transportation time per project. Distances ranged from more than a hundred miles such as landfill cover at distant sites and reclamation at mines on the Iron Range to projects in direct proximity to Erie Pier and the Duluth-Superior Harbor, such as Sky Harbor Airport and the CN Railroad Ore Docks.

Discussion of possible projects also included the perception that the scale of the project (in cubic yards) is of interest, given the amount of material currently stock piled at the CDF. The estimation of project scale in terms of cubic yards was presented and ranked by demand in cubic yards. Based on assumptions suggested in phone interviews with possible customers, total cubic yards of demand per project ranged from nearly six thousand cubic yards (for small-scale mine reclamation test-projects) to a million cubic yards (for construction fill associated with power plant development).

Recurring projects were found to be of interest given the finding that distance and time are greater drivers of cost than scale. Recurring projects lend themselves to getting the existing material out. Non-recurring projects assume the use of subsequent years' dredging (to avoid moving material twice). Erie Pier managers may need to establish an optimal steady-state between recurring and non-recurring re-use projects for fines material.

Although many customers have alternatives to using Erie Pier materials, among the most competitive attributes of the fines materials are: 1) easy access to site from I-35 with the possibility of improved infrastructure so that rail could be used to transfer large quantities, 2) a product relatively free of contaminants such as heavy metals and present but manageable noxious weed infestation, and 3) the price for material as a commodity could be minimal, or zero for the customer.

Important competitive disadvantages of Erie Pier fines material include 1) the fact that customers may be unaware of materials and its availability, 2) seasonality of the site with regard to dewatering, dredging scheduled and climate related hardships, 3) regulation requirements, 4) application difficulties related to the clay component of the fines material, 5) tipping fees, and 6) the possible need for public funding to improve the site and accessibility to materials.

### 1.3 Cost Analysis

Two estimates were presented in the Phase I report. The first estimate is for total cost of fixed and variable costs. The second estimate is for incremental or out-of-pocket costs for fixed and variable costs. These two analyses differentiate between 1) purchasing new equipment for the facility, and 2) using existing equipment.

Cost-Volume-Profit (or break-even without revenues) calculations are based on an identification of the total costs. We identify the cost per yard to move a specific amount at a specific distance, in order to estimate the least cost per yard. This calculation also suggests the appropriate subsidy to cover that cost.

The analyses show that the faster the trucks move, the farther out it is cost-effective to truck the material. A calculation for total cost and incremental cost shows at what point it is cost effective to switch to RailMate™ which connects multiple semi-trailers to a train for a point-to-point road to rail delivery of commodity products. (As a practical limitation, this is feasible only if you have access to a railroad and the RailMate technology.): The Total Cost turning point to switch from truck to RailMate, at 40 MPH, intersects RailMate at 101.56 miles; and at 50 MPH, intersects RailMate at 128 miles. The Incremental Cost turning point to switch from truck to RailMate, at 40 MPH, intersects RailMate at 101.56 miles; at 50 MPH, intersects RailMate at 128 miles.

The total landed cost per yard for the RailMate System, or the cost per yard to move the material via the RailMate system for distances of 100, 150, and 200 miles (no data for 50 miles) was estimated at $19.44 per cubic yard. The total landed trucking cost per yard, or the cost per yard to move the material via a truck at a given average speed for a given distance, with one half hour of transit time to the move for loading and unloading, is estimated at between $16.33 and $49.67 for speeds of 25 MPH; at between $12.17 and $33.00 for speeds of 40 MPH; and between $10.78 and $27.44 for speeds of 50 MPH.

The incremental (out-of-pocket) landed cost per yard for the RailMate System, or the cost per yard to move the material via the RailMate system for distances of 100, 150, and 200 miles (no data for 50 miles) was estimated at $18.73 per cubic yard. The total landed trucking cost per yard, or the cost per yard to move the material via a truck at a given average speed for a given distance, with one half hour of transit time to the move for loading and unloading, was estimated at between $15.62 and $48.96 for speeds of 25 MPH; between $11.46 and $32.29 for speeds of 40 MPH; and between $10.07 and $26.73 for speeds of 50 MPH.

The cost analysis showed that the decision to use a particular transportation system will be predicated first by the distance of the customer from Erie Pier. Phase I analyses found that at 200 miles total distance, it will always be more cost effective to utilize the RailMate system. At 150 miles, it will likewise be cost effective to use the RailMate system. At 100 miles, efficiency depends on the assumed speed of the truck. If the speed is less than 50 MPH, it is more cost effective to use the RailMate system. If one is using incremental costs, it is better to use a truck at any speed greater than 40 MPH and at 100 miles distance. At a total distance of 50 miles it appears to be more cost effective to use trucking, although there is no data on the cost of using RailMate at distances less than 100 miles.

The findings of the cost analysis in Phase I were presented as useful for an estimation of least cost alternatives. In evaluating whether to build a new CDF one must first consider the cost of a new facility. The USACE estimates that it would cost (in today's dollars) $30,000,000 to build a new CDF. However, this cost does not include externality costs, which could double or triple the estimated cost. These external costs are difficult to estimate and can be subjective in nature, and the cost benefit analysis necessary to estimate these external costs is not within the scope of this project. The cost of building a new facility also assumes, perhaps incorrectly, that it would be politically possible to situate a new CDF in the Duluth-Superior Harbor.

Presently there are not more than 1,500,000 cubic yards total of material in the Erie Pier facility. The estimation of least cost could suggest that a realistic scenario would be to remove 100,000 cubic yards per year. This would take a total of 15 years to draw down the quantity in Erie Pier to zero stored on site. Fifteen years is therefore used as the discount period in doing present value calculations. An appropriate discount rate is 4%. This is consistent with historical trends. The most conservative estimate of annual operating costs to remove the 100,000 cubic yards and transport it a total of 200 miles is $2,673,000 per year.

The Phase I report shows that the present value of an annuity of $2,673,000 at 4% for 15 years is $29,719,450. This would indicate that it is slightly less expensive to remove the materials than it is to build a new facility. If one considers externality costs, it is clear that the low-cost alternative is to remove the materials from the site and not wait to build a new facility.

In addition, Phase I also found that the cost of imminent alternatives could include finding low-cost ways to take the current dredged material to other locations. This could assume no additional capital costs, no railroad spur, and no other new technologies except the possible inclusion of RailMate. (In these scenarios, there would be no added fixed costs.)

### 1.4 Conclusions

The Phase I report considered the usefulness of this study for other Great Lakes ports. It was noted that the Duluth-Superior port may be unique in some ways from other ports. For instance, in the Duluth Harbor, dredged materials are not significantly polluted, the seasonality of port activity is a significant factor, and re-use projects have been already considered and in some cases plans are under discussion.

However, the following points from the Phase I study may be of interest to other ports on the Great Lakes:

- Transportation costs should be considered (almost) the entire cost.
- Feasible customers have competing suppliers.
- Given a CDF with a short remaining life, non-recurring projects of most interest will be long-term projects near the CDF (or new PRF), and include using largest amounts of material (wetlands and habitat creation).
- Timing of opportunities can be crucial; the business cycle of the customer is significant.
- Minimizing transportation time is the most cost effective principle.
- Cost-per-yard shows what the government (or other funder) might be willing to subsidize.
- Assume that choosing customer(s) who will take the maximum yards doesn't compare with the cost saving of using a closest customer.

Finally, without the availability of a complete impact study, it was noted that the largest economic impact may be attributed to a change in how Erie Pier and other Great Lakes ports view CDFs. Erie Pier should be viewed as a Process Re-use Facility, or PRF. This switch would result in turning a current environment disposal problem into an economic impact or benefit. The PDF would generate much more positive economic activities and benefits. The “greening” of the CDF will create products that will meet the demands of the construction, habitat creation and restoration, agriculture, forestry, and mining industries.

Dredging, processing and transporting the Erie Pier materials will generate direct, indirect and induced economic impacts. The direct impacts will be created in the dredging, processing and transportation sectors. Their expenditures will result in new business-to-business spending, or indirect impacts. These indirect impacts would include increased activity in sectors such as fuel supply and maintenance and repair services. In addition, the workers in these impacted industries would spend their wages and create new induced impacts.

A second phase of this project was proposed to model and identify the most cost-effective way(s) to transport dredged materials to customers. The continuing study investigates how to control operating costs for Erie Pier CDF by optimizing the handling and distribution of re-use of dredged material.

# 2. Analysis

## 2.1 Problem Statement

The objective of this Phase II project is to determine in what transportation mode the fine materials should be shipped to which customers in order to minimize the overall transportation cost while depreciating most, if not all, of the accumulated and recurring fine materials, in order to turn Erie Pier into a reuse facility. Optimal year-by-year plans that guide the transportation of fine materials to the chosen customers in twenty one years will also be created.

## 2.2 Data Collection and Assumptions

### 2.2.1 Customer Information

All of the feasible long-term and short-term customers identified in the Phase I project were considered in this project. Table 2.1 lists the long term customers along with their industry sector in relation to their usage of fine materials, distance from each customer to Erie Pier, and each customer's total demand of fine materials. All the long-term customers are considered as non-recurring projects since they have a one-time demand. Table 2.2 lists the short term customers with the same configuration of variables. The single difference is that the short-term customers all have projects that recur yearly, which means the demand is understood to be annual demand.

**Table 2. 1 Long-Term Customer Options**

| Industry Sector | Customer | Distance from Erie Pier (Miles) | Total Demand (Cubic Yards) |
|---|---|---|---|
| **Construction Fill** | CN Railroad Ore Docks | 2.2 | 900,000 |
| **Construction Fill** | Sky Harbor Airport | 7.4 | 250,000 |
| **Construction Fill** | Hibbard Power Plant | 2.8 | 1,000,000 |
| **Soil Enrichment** | Wetlands Habitat 21st Ave. W Project (Duluth) | 1.2 | 950,000 |

**Table 2. 2 Short-Term Customer Options**

| Industry Sector | Customer | Distance from Erie Pier (Miles) | Annual Demand (Cubic Yards) |
|---|---|---|---|
| **Soil Enrichment** | Wrenshall Farming | 22.8 | 64,560 |
| **Soil Enrichment** | Floodwood Farming | 44.4 | 64,560 |
| **Land Fill** | Wisconsin Waste Management | 4.6 | 21,207 |
| **Land Fill** | Waste Management (Canyon, MN) | 29.8 | 21,207 |
| **Land Fill** | Waste Management (Elk River, MN) | 163.0 | 21,207 |
| **Mine Reclamation** | Keewatin Taconite | 81.6 | 8,873 |
| **Mine Reclamation** | United Taconite | 60.0 | 8,873 |

**Table 2. 3 Additional Information (Waste Management - Canyon, MN)**

| Waste Management (Canyon, MN) Additional Information | |
|---|---|
| **Waste Management Land Fill Accommodations per Day** | 70 tons (58.1 cubic yards) |

The landfill near Canyon, MN is a 100-acre clean industrial/demolition debris landfill. The operation is capable of accepting about 70 tons of material per day. This is shown above in Table 2.3. In the past two years, the Superior landfill has started to charge a tipping fee to Wisconsin Waste Management for each truckload. This fee is approximately $100 per truckload, as shown in Table 2.4.

**Table 2. 4 Additional Information (Wisconsin Waste Management)**

| Wisconsin Waste Management Additional Information | |
|---|---|
| **Tipping Fee per Truckload** | $100 |

Wrenshall farming is able to apply Erie Pier fines material at a rate of about 50 cubic yards per acre. Additional costs of applying the material into the soil, including labor and equipment, could be about $55 per acre. Dividing the application cost per acre by the application rate gives an application cost per cubic yard of about $1.10. Floodwood farming also has additional costs associated with the project, in terms of tillage and seeding. Additional costs per day are $100. This information is summarized in Tables 2.5 and 2.6.

**Table 2. 5 Additional Information (Wrenshall Farming)**

| Wrenshall Farming Additional Information | |
|---|---|
| **Application Rate (Cubic Yards/Acre)** | 50 |
| **Additional Cost to Apply Material (per Acre)** | $55 |
| **Application Cost (per Cubic Yard)** | $1.10 |

**Table 2. 6 Additional Information (Floodwood Farming)**

| Floodwood Farming Additional Information | |
|---|---|
| **Tillage and Seeding (Cost per Day)** | $100 |

### 2.2.2 Supply Information at Erie Pier

Table 2.7 shows the estimated volume of both coarse and fine material available annually, as well as the current total accumulation of removable fines at Erie Pier. Also listed is the estimated maximum allowable removal of materials per year. The consumption of fines is of most concern due to the fact that the coarse material (or sand) is a more desirable commodity and the CDF has a history of selling these materials to local contractors for various purposes. Therefore, this project focuses on the removal of fine materials.

**Table 2. 7 Volume of Dredged Material at Erie Pier**

| Material | Recurring Yearly Total | Total Accumulation to Date |
|---|---|---|
| **Coarse Material** | 48,000 cubic yards | |
| **Fines Material** | 50,000 cubic yards | |
| **Removable Fines** | | 1,250,000 cubic yards |
| **Maximum removable of materials per year: 100,000 cubic yards*** | | |
| **Density of fines: 1.29 tons / cubic yard (16.5%-17.5% moisture level)** | | |

**This assumption was modified later in the analysis part to create different scenarios*

In addition to the estimation of availability of fines and coarse material at Erie Pier, the density of the fines is assumed to be 1.29 tons/cubic yard at 16.5% to 17.5% moisture level. This is later used to convert between the volume in cubic yards and the weight in tons for various calculations.

### 2.2.3 Transportation and Equipment Cost

Price quotes from two truck companies, Lakehead Trucking and Udeen Trucking, were acquired. Their information is summarized in Tables 2.8 and 2.9. The Lakehead Trucking option offers a basic charge of $2.25 per cubic yard mile. These trucks can carry various volumes depending on the condition of the material. For example, as shown in Table 2.8, Lakehead trucks can carry 18 cubic yards per load of dry material, 15 cubic yards per load of damp material, and 14 cubic yard per load of wet material.

Table 2. 8 Lakehead Trucking Information and Costs

| Lakehead Trucking Option | | |
|---|---|---|
| **Transportation Costs (per cubic yard mile)** | | $2.25 |
| **Capacity (cubic yards per truck load)** | Dry Material | 18 |
| | Damp Material | 15 |
| | Wet Packed Material | 14 |
| **Loading and Unloading Time of Truck (hours)** | | 0.5 |
| **Transit Costs (at $100/hour)** | | $50 |
| **Miles from Erie Pier** | | 17.7 |

The Udeen Trucking option, shown in Table 2.9, offers two types of trucks, the quad trucks and end dump trucks, each with different basic charges. Like Lakehead Trucking, Udeen Trucking can handle various loads of material. However, this is dependent on the trucking route. Minnesota load restrictions only allow quad trucks to carry 14 cubic yards per load, where end dump trucks can carry 20 cubic yards per load.

Table 2. 9 Udeen Trucking Information and Costs

| Udeen Trucking Options (Quad and End Dump) | |
|---|---|
| ***Quad Truck*** | |
| **Costs Per Hour** | $90 |
| **Cubic Yards per Load (Minnesota)** | 14 |
| **Cubic Yards Per Load (Wisconsin)** | 17 |
| **Loading and Unloading Time of Truck (Hours)** | 0.5 |
| **Transit Costs (at $90/hour)** | $45 |
| ***End Dump Truck*** | |
| **Costs Per Hour** | $100 |
| **Cubic Yards per Load** | 20 |
| **Loading and Unloading Time of Truck (Hours)** | 0.5 |
| **Transit Costs (at $100/hour)** | $50 |
| **Miles from Erie Pier** | 9.3 |
| **Hours from Erie Pier (at 40 MPH)** | 0.23 |

Price quotes for using the RailMate system to transport the fine materials is summarized in Table 2.10. The owner of the RailMate system, American Surface Lines, LLC is willing to haul the dredged materials at a unit cost of $17/ton to customers located within 30 miles of the rail track, regardless of the total delivery distance.

Table 2. 10 RailMate System Information and Costs

| RailMate System Option | |
|---|---|
| Within 30 Miles to a Rail track | $17/ton |
| Beyond 30 Miles to a Rail track | No Data |

It is assumed that customers are responsible for loading and unloading the material in all the cases. For loading and unloading, bulldozers and loaders will be needed. The estimated cost of equipment purchase and operation are summarized in Table 2.11.

Table 2. 11 Estimation of Landed Cost Using Total Cost Assumptions

| Fixed and Variable Total Cost Assumptions | |
|---|---|
| **Available Bulldozers at Erie Pier** | 3 |
| **Available Loaders at Erie Pier** | 3 |
| **Remaining Useful Life of Existing Bulldozers** | Half |
| **Remaining Useful Life of Existing Loaders** | Half |
| **Useful Life of Machines (Hours)** | 12,500 |
| **Bulldozer Purchase Price** | $200,000 |
| **Loader Purchase Price** | $200,000 |
| **Hourly Operating Costs (Bulldozer and Loader)*** | $110 |
| **Number of Trucks Loaded per Hour** | 5 |

**Hourly Operating Costs based on "Pay and Benefits" ($54), "Fuel" ($24), and "Depreciation (per hour)" ($32)*

The hourly operating cost for the bulldozers and the loaders is $110, which includes operator pay and benefits, fuel, and depreciation. Bulldozers and loaders each cost $200,000. The useful life of each machine is approximately 12,500 hours. It is assumed that 3 bulldozers and 3 loaders are available at the pier and each has half the useful life remaining.

Table 2. 12 Working Assumptions at Erie Pier

| Project Working Assumptions | |
|---|---|
| **Work Hours per Day** | 10 |
| **Work Days per Year** | 304* |

**This assumption was modified later in the analysis part to create different scenarios*

The assumptions made in Table 2.12 correspond to the number of working days per year and the number of hours worked per working day. These values are based on average construction-worker schedules. However, since the accessibility of Erie Pier may not be year round, and to avoid interference with the dredging activities, this assumption is modified in scenario analysis.

### 2.3 Pre-screening of transportation methods

Initially, three transportation modes (rail plus truck; truck only; and the RailMate system) are evaluated. To simplify the analysis, a pre-screening of these three transportation modes is conducted to eliminate any obviously inferior solutions. This resulted in the elimination of the "rail plus truck" option since it provides an obviously inferior solution to the RailMate option. As compared to RailMate, the rail plus truck option involves the following areas of concern:

1) Higher $/ton unit transportation cost on rail and on road: It is quite difficult to get an accurate quote for the unit cost on rail transportation. However, based on information acquired, it is for sure that such unit cost will be greater than or at least equal to the unit cost of using RailMate.

2) Three times of loading and unloading cost: Even though Erie Pier is located very close to rail tracks, materials still need to be loaded to trucks, transported to the rail station, unloaded from the truck, and loaded to the rail cars. Then the materials will be shipped by rail to a rail station that is closest to the customers. Since no customer is located right on a rail station, the materials need to be again unloaded from the rail cars, loaded to the trucks, transported to the customer destination even though this can be very short distance to a few customers, and finally be unloaded from the truck at the destination. Even if a customer currently has a rail track built to go into its facility, it

is less likely that the ending point of the track is right at where the fine materials will be used. Therefore, the loading and unloading is not avoidable unless the bulldozers and loaders are used to carry the materials to the destination. In this case, the loading and unloading will be two times as compared to using the RailMate system. However, more cost will occur to operate the loading equipment.

3) Hidden costs: For example, dealing with truck companies and rail carriers for individual contracts and taking care of the inter-modal scheduling. Getting rate quotes can be difficult, until you get an actual cargo, and can sometimes change on an hourly basis. Conversion into other units can be difficult, given various sizes and types of vehicles. Other costs and transportation impacts to consider are air pollution; fuel costs; wear and tear on roads, highways and bridges; navigating construction detours and traffic congestion; managing noise; special restrictions for heavy trucks traveling within city limits; weather restrictions; and road repairs required for maintenance at Erie Pier.

4) High cost of transfer yard: A transfer yard is required if rail cars need to be unloaded and switched to a different track. It is estimated that 6-18 million dollars and up to five years are needed to acquire a transfer yard permit. This part will be saved using RailMate instead of rail plus truck option.

The RailMate system is an innovative way of transporting commodities by combining the advantages of truck and rail transportation. American Surface Lines, LLC, has designed bogies that can easily convert an end-dump trailer into a rail car in 8 minutes. It eliminates the high costs involved in the loading and unloading between trucks and rail cars of inter-modal transportation. Since only 132 feet of flat surface is needed to transfer a trailer, the conversion can be done not only at designated rail stations but also at rail track locations that are closer to customers. With this innovative solution, the American Surface Lines, LLC is willing to haul the dredged materials at a unit cost of $17/ton to customers located within 30 miles of the rail track regardless of the total delivery distance.

## 2.4 Cost Calculation

With the “rail plus truck” option eliminated, two transportation modes were left in the analysis. Since no obvious comparison conclusion can be drawn at this stage, both options are included in the optimization modeling. Before the modeling stage, the overall transportation costs for each of the potential customers with truck options were identified based on price quotes from the two truck companies, as well as on additional mileage identified from Google Maps. Table 2.13 lists the distance from each customer to Erie Pier and the two truck companies.

Table 2. 13 Distance and Travel Time from Customers to Erie Pier and Truck Companies

| Customer List | Miles from Erie Pier | Travel Time (hr) | Miles from Lakehead | Travel Time (hr) | Miles from Udeen | Travel Time (hr) |
|---|---|---|---|---|---|---|
| **Keewatin Taconite (Keetac)** | 81.6 | 2.04 | 83.9 | 2.10 | 89.0 | 2.23 |
| **United Taconite (UTAC)** | 60.0 | 1.5 | 55.0 | 1.38 | 64.7 | 1.62 |
| **Waste Management (Superior)** | 4.6 | 0.12 | 21.0 | 0.53 | 4.3 | 0.11 |
| **Waste Management (Canyon)** | 29.8 | 0.75 | 23.6 | 0.59 | 33.3 | 0.83 |
| **Waste Management (Elk River)** | 163.0 | 4.08 | 179.0 | 4.48 | 174.0 | 4.35 |
| **Floodwood Farmers** | 44.4 | 1.11 | 43.0 | 1.08 | 49.9 | 1.25 |
| **Wrenshall Farmers** | 22.8 | 0.57 | 33.1 | 0.83 | 16.5 | 0.41 |
| **Sky Harbor Airport** | 7.4 | 0.19 | 11.8 | 0.30 | 14.9 | 0.37 |
| **Hibbard Power Plant** | 2.8 | 0.07 | 19.5 | 0.49 | 8.0 | 0.20 |
| **CN Railroad Ore Docks** | 2.2 | 0.06 | 19.0 | 0.48 | 8.7 | 0.22 |
| **21st Ave W Project** | 1.2 | 0.03 | 16.0 | 0.40 | 8.9 | 0.22 |

Using such information together with the customer demand, workable days per year, workable hours each day, and capacity of each truck option, individual spreadsheets were created to determine the number of trucks that each customer should use to minimize costs and then calculate the cost of serving each customer with each truck option. Due to the assumption that five trucks can be loaded every hour, trucks from Lakehead or Udeen should be transported to Erie Pier in sets of five at one-hour intervals to prevent the occurrence of a bottleneck in the system. Then the number of truckloads required per day to complete the project of each customer was determined. Table 2.14 shows an example of the truck schedule for Wisconsin Waste Management in Superior.

**Table 2. 14 Truck Schedule Example of Serving Wisconsin Waste Management in Superior**

| Time | Sent from Trucking | Sent from E.P. | Arrive at WM (Superior) | Arrive at E.P. | Return to Trucking |
|---|---|---|---|---|---|
| 8:00 | 5 | | | | |
| 8:30 | | | | | |
| 9:00 | | 5 (Udeen) | 5 (Udeen) | | |
| 9:30 | | 5 (LH) | 5 (LH) | | |
| 10:00 | | | | 5 (Udeen) | |
| 10:30 | | | | 5 (LH) | |
| 11:00 | | 5 (Udeen) | 5 (Udeen) | | |
| 11:30 | | 5 (LH) | 5 (LH) | | |
| 12:00 | | | | 5 (Udeen) | |
| 12:30 | | | | 5 (LH) | |
| 1:00 | | 5 (Udeen) | 5 (Udeen) | | |
| 1:30 | | 5 (LH) | 5 (LH) | | |
| 2:00 | | | | 5 (Udeen) | |
| 2:30 | | | | 5 (LH) | |
| 3:00 | | 2 to 5 (Udeen) | 2 to 5 (Udeen) | | |
| 3:30 | | 2 to 5 (LH) | 2 to 5 (LH) | | |
| 4:00 | | | | | 5 (Udeen) |
| 4:30 | | | | | |
| 5:00 | | | | | 5 (LH) |
| 5:30 | | | | | |
| 6:00 | | | | | |

Based on this information and the total demand of each customer, the total number of trucks required to complete each project can be determined. As a result, the total transportation cost using each truck option can also be calculated. Based on the assumption that only one transportation method will be used for each project to avoid multiple contracts with different companies, the total cost for completing each project using each transportation option was determined individually. To determine the transportation cost of shipping the fines to customers using RailMate, customer demand in cubic yard was converted to tons based on the density of the material since RailMate charge by $/ton. Then each customer was located on Google map to make sure that all of them are within 30 miles to a rail track.

[The spreadsheets used to calculate the transportation cost for each individual customer with each transportation option, and maps showing each individual customer and the close-by rail track are available on request.]

Since RailMate charges by $/ton to transport the dredged materials from Erie Pier to the customers' locations, the company will take care of the scheduling of truck drivers for the road transportation part. Therefore, we don't need to do the same kind of scheduling analysis as what we did for the trucking option.

Several customers, such as CN Railroad Ore Docks, Hibbard Power Plant, $21^{st}$ Ave W. Project, and Wisconsin Waste Management in Superior, are located within 10 miles of Erie Pier, and no rail transportation is really needed. Since the unit transportation price quoted from the truck companies and the RailMate company are in different formats—one is charged at $/hour of driving time and the other $/ton of material shipped—a direct comparison between the two transportation methods is not obvious. Therefore, the model includes RailMate as a possible transportation option for all projects. In case RailMate is suggested as the optimal transportation option for any short-distance projects, RailMate only needs to contract drivers to perform road transportation, and rail transportation and changing gears can be avoided. Or the same project(s) can be served by a truck company if the same or a better bargain can be agreed on.

## 2.5 Model Building

The next step involved building optimization models to identify the best combination of projects, the optimal number of recurring years for any chosen short-term recurring projects, and the shipping plan in each year, to minimize the overall project costs while diminishing most of the fine materials. Transportation costs calculated in the previous section, as well as the additional equipment and project costs are used in calculating the total project costs and determining the optimal transportation plan. The optimization modeling was separated into two stages, with the first stage identifying which customers to serve and by what transportation mode and the second stage determining the year-by-year transportation plan. This was to avoid using a non-liner programming model in which the global optimal solution is not guaranteed.

### 2.5.1 Stage 1 Model

The decision variables for this problem consist of $X_{ij}$ and $Y_i$, both of which are binary variables. The subscript "i" is represented by values 1 through 11 in accordance to the project options. The "j" subscript is defined as 1 to 3 by each of the trucking options, plus 4 representing the RailMate system, respectively. If $X_{ij}$ is equal to 1, then the project option "i" is selected and fines will be shipped to this customer by transportation option "j." If an X variable is equal to zero, then project option "i" and its corresponding transportation option "j" are not selected. If $Y_i$ is equal to 1, then project "i" is selected, and if it equals to 0, then the project is not selected. Other important variables include: $C_{ij}$, which represents the total transportation costs for project option "i" with transportation option "j;" $N_i$, the minimum number of years to complete project "i", based on the demand of project "i" and the maximum amount of cubic yards that can be removed in each year; $D_i$, the total cubic yards of material demanded by each project I; and $TL_{ij}$, the number of truckloads needed for project i serving with truck option j.

The objective function is to minimize the overall costs for all projects selected. It consists of multiple types of costs, including the following: transportation costs, operating costs, equipment costs, loading costs, and other additional costs for specific projects. The first set of costs is the transportation costs (trucking or RailMate) for each selected project and trucking/rail option. Each transportation option that is selected has a corresponding total cost associated with that option. Since the transportation costs have been defined in the preparation stage, they are readily usable and are referred to in the models.

The operating costs of the bulldozers and loaders and the minimum number of years they will operate for the selected project are calculated in this stage. The hourly cost to run this equipment is $110 which includes pay and benefits, fuel, and depreciation per hour. It was assumed that each piece of equipment will operate for 10 hours a day and will run for approximately 304 days a year which was determined by six-day work weeks minus 8 holidays. It was also assumed that there needs to be at least 3 bulldozers and 3 loaders at all times in order to load 5 trucks/trailers per hour. Each new bulldozer or loader costs

$200,000 and has a useful life of 12,500 hours. The three bulldozers and three loaders that are currently on hand were assumed to have half their operating life left. In addition to the cost to operate the bulldozers and loaders, an incremental loading cost $1.73 per cubic yard is also assumed based on calculations in Phase I of this project. Additional possible costs include: Wisconsin Waste Management has an additional cost known as a tipping fee which consists of $100 extra charge per truckload for the corresponding project; The Wrenshall farming project has an additional cost of $1.10 per cubic yard; The Floodwood farming project has an additional cost for tillage and seeding of $100 per year.

There are many constraints that need to be met for this problem based on the cost analysis and other assumptions made for the defined scope. The first constraint is that the total cubic yards of fine material from all selected project option needs to be greater than or equal to 90% of the total fine material (current fines plus recurring) so that most of the fine material will be eliminated. An additional constraint to this situation is that the total cubic yards must be less than or equal to the total accumulated fine materials since it is not possible to transfer more material than is available. According to the project assumptions, Erie Pier can select multiple long-term projects which means that the sum of $Y_i$ is greater than or equal to one where "i" is 8 to 11. The remaining materials after the long-term project will be taken care of by the short-term projects. This means the sum of all the short-term projects $Y_i$, where "i" is 1 to 7, needs to be greater than or equal to zero. It was also assumed that one trucking option, or RailMate system if applicable, would be used per selected project to avoid multiple contracts with different transportation companies. Therefore, the sum of each transportation option for each corresponding project option has to be less than or equal to one. There are two sets of linking constraints for this project that apply to each of the 11 potential projects. The first set of linking constraints is set for when a project is chosen ($Y_i$ equals 1), and then the best trucking option is chosen. If a trucking option is not chosen, then the truck option is equal to zero. The second set of linking constraints is used to ensure that each selected project has some form of transportation. This means that if project "i" is selected, the sum of each transportation option for that project has to be equal to 1. Otherwise, if the project is not chosen then the sum of the transportation options has to be zero. The model formulation of these decision variables, objective function, and constraints are presented below.

***Decision Variables***:

$X_{ij} = 1$ if Project i is selected to be served by Truck option j

$X_{ij} = 0$ if Project i is not selected to be served by Truck option j

$Y_i = 1$ if Project i is selected $(i = 1 - 11)$

$Y_i = 0$ if Project i is not selected $(i = 1 - 11)$

$i = 1 - 11$

1 = Keewatin Taconite (Keetac)

2 = United Taconite (UTAC)

3 = Wisconsin Waste Management

4 = Waste Management (Canyon, MN)

5 = Waste Management (Elk River, MN)

6 = Wrenshall Farmers

7 = Floodwood Farmers

8 = 21st Ave. W Project

9 = CN Railroad Ore Docks

10 = Hibbard Power Plant

11 = Sky Harbor Airport

$j = 1 - 4$

1 = Lakehead Trucking

2 = Udeen (Quad)Trucking

3 = Udeen (End − Dump)Trucking

4 = RailMate System

*Additional Variables*:

$C_{ij}$ = Total Transportation Costs for Project i served by Transportation Option j (i = 1 − 11, j = 1 − 4)
$N_i$ = Minimum Number of Years to Complete Project i (i = 1 − 11)
$D_i$ = Anual Demand of Fine Materials for Recurring Project i in Cubic Yards (i = 1 − 7)
$D_i$ = Total Demand of Fine Materials for Project i in Cubic Yards (i = 8 − 11)
$TL_{ij}$ = Number of Truckloads required for Project i (i = 1 − 11) Served by Truck Option j (j = 1 − 3)
$R_i$ = Number of Recurring Years for Project i (i = 1 − 7)
TY = Total Number of Years to Complete Selected Projects
MCY = Maximum removable of Fines per Year

**Objective Function:**

$$\text{MIN:}\left(\sum_{j=1}^{4}\sum_{i=1}^{11} C_{ij}\times X_{ij}\right)+\left((110\times 10\times 304)\times\sum_{i=1}^{11} N_i\times Y_i\right)+2\times\left(200{,}000\times\frac{\left(\left(\sum_{i=1}^{11} N_i\times Y_i\right)\times 10\times 304\right)-3\times 6{,}250}{12{,}500}\right)+\left(100\times(TL_{31}+TL_{32}+TL_{33})\times Y_1\right)+(1.10\times D_6\times Y_6)+(100\times N_7\times Y_7)+\left(1.73\times\sum_{i=1}^{11} D_i\times Y_i\right)$$

**Constraints**

Subject to:

$$0.90\times\left(1{,}250{,}000+(50{,}000\times TY)\right)\le\sum_{i=1}^{11} D_i\times Y_i\le\left(1{,}250{,}000+(50{,}000\times TY)\right)$$

$0 \le Y_1 - X_{1,1} \le 1$ $0 \le Y_1 - X_{1,2} \le 1$ $0 \le Y_1 - X_{1,3} \le 1$ $0 \le Y_1 - X_{1,4} \le 1$
$0 \le Y_2 - X_{2,1} \le 1$ $0 \le Y_2 - X_{2,2} \le 1$ $0 \le Y_2 - X_{2,3} \le 1$ $0 \le Y_1 - X_{2,4} \le 1$
$0 \le Y_3 - X_{3,1} \le 1$ $0 \le Y_3 - X_{3,2} \le 1$ $0 \le Y_3 - X_{3,3} \le 1$ $0 \le Y_1 - X_{3,4} \le 1$
$0 \le Y_4 - X_{4,1} \le 1$ $0 \le Y_4 - X_{4,2} \le 1$ $0 \le Y_4 - X_{4,3} \le 1$ $0 \le Y_1 - X_{4,4} \le 1$
$0 \le Y_5 - X_{5,3} \le 1$ $0 \le Y_5 - X_{5,4} \le 1$
$0 \le Y_6 - X_{6,1} \le 1$ $0 \le Y_6 - X_{6,2} \le 1$ $0 \le Y_6 - X_{6,3} \le 1$ $0 \le Y_1 - X_{6,4} \le 1$
$0 \le Y_7 - X_{7,1} \le 1$ $0 \le Y_7 - X_{7,2} \le 1$ $0 \le Y_7 - X_{7,3} \le 1$ $0 \le Y_7 - X_{7,4} \le 1$
$0 \le Y_8 - X_{8,1} \le 1$ $0 \le Y_8 - X_{8,2} \le 1$ $0 \le Y_8 - X_{8,3} \le 1$ $0 \le Y_1 - X_{8,4} \le 1$
$0 \le Y_9 - X_{9,1} \le 1$ $0 \le Y_9 - X_{9,2} \le 1$ $0 \le Y_9 - X_{9,3} \le 1$ $0 \le Y_1 - X_{9,4} \le 1$
$0 \le Y_{10} - X_{10,1} \le 1$ $0 \le Y_{10} - X_{10,2} \le 1$ $0 \le Y_{10} - X_{10,3} \le 1$ $0 \le Y_1 - X_{10,4} \le 1$
$0 \le Y_{11} - X_{11,1} \le 1$ $0 \le Y_{11} - X_{11,2} \le 1$ $0 \le Y_{11} - X_{11,3} \le 1$ $0 \le Y_1 - X_{11,4} \le 1$

$(X_{1,1} + X_{1,2} + X_{1,3} + X_{1,4}) - Y_1 = 0$
$(X_{2,1} + X_{2,2} + X_{2,3} + X_{2,4}) - Y_2 = 0$
$(X_{3,1} + X_{3,2} + X_{3,3} + X_{3,4}) - Y_3 = 0$
$(X_{4,1} + X_{4,2} + X_{4,3} + X_{4,4}) - Y_4 = 0$
$(X_{5,3} + X_{5,4}) - Y_5 = 0$
$(X_{6,1} + X_{6,2} + X_{6,3} + X_{6,4}) - Y_6 = 0$

$(X_{7,1} + X_{7,2} + X_{7,3} + X_{7,4}) - Y_7 = 0$
$(X_{8,1} + X_{8,2} + X_{8,3} + X_{8,4}) - Y_8 = 0$
$(X_{9,1} + X_{9,2} + X_{9,3} + X_{9,4}) - Y_9 = 0$
$(X_{10,1} + X_{10,2} + X_{10,3} + X_{10,4}) - Y_{10} = 0$
$(X_{11,1} + X_{11,2} + X_{11,3} + X_{11,4}) - Y_{11} = 0$
$N_i = D_i / MCY$
$X_{ij}, Y_i$ Binary

### 2.5.2 Stage 2 Model

Based on results from the stage 1 model, a second stage model was built to create the year-by-year plan that guides the shipment of fines to each identified customer in each chosen year. Decision variables for this model include $CY_{ijk}$ and $Z_{ijk}$; the first representing the total cubic yards for non-recurring projects and the latter representing the recurring projects as a binary variable. $CY_{ijk}$ is the total cubic yards of fine materials shipped for project option "i" with transportation option "j" during year "k". The $Z_{ijk}$ variable is binary and defines if a recurring project is selected in year "k:" If it equals to "1", the recurring project is chosen; if it equals "0", it is not selected.

Besides the variables defined in the previous model, additional variables used include: unit transportation cost of shipping by truck or RailMate, denoted as $C_{ij}$, and the maximum level of removable fines in year k, denoted as $MCY_k$. The real interest rate, which includes inflation and interest, is assumed to be 4.0%.

The objective function is to minimize the present value of the total transportation and material handling costs. The first constraint ensures that the total removed fines in a given year do not exceed the maximum removable fines. It must also be guaranteed that the customer demand is met. Therefore, constraints are set in place to make sure that the sum of fines transported to a certain long term customer in all the chosen years equals to such customer's demand, and the fines transported to a recurring customer in a certain year either equals to zero or the demanded amount. Since the results from stage one suggest that for each chosen short-term customer, the optimal recurring year is five, therefore, an additional constraint guarantees that the number of recurring years for each short-term customers is five.

The model formulation of the decision variables, objective function, and constraints are presented below.

**Decision Variables:**

$CY_{ijk}$ = Total Cubic Yards of Fines for Project i with Transportation Option j during year k
$Z_{ijk}$ = 1 if Project i with Transportation Option j is selected in year k
$Z_{ijk}$ = 0 if Project i with Transportation Option j is not selected in year k
$C_{ij}$ = Unit Cost for Project i with Transportation Option j
$MCY_k$ = Maximum Removable Fines in year k
$i'$ = Real interest rate (inflation + interest) − assumed to be 4.0%
$D_i$ = Anual Demand of Fine Material for Recurring Project i in Cubic Yards
$R_i$ = Number of Recurring Years for Project i
TY = Total Number of Years to Complete Selected Projects
E = Total Equipment Costs
$N_i$ = Minimum Number of Years to Complete Project Option i $(i = 1 - 11)$
A = Total Additional Costs
L = Total Loading Costs

Where
$i = 1 - 11$

1 = Keewatin Taconite (Keetac)
2 = United Taconite (UTAC)
3 = Wisconsin Waste Management
4 = Waste Management (Canyon, MN)
5 = Waste Management (Elk River, MN)
6 = Wrenshall Farmers
7 = Floodwood Farmers
8 = 21st Ave. W Project
9 = CN Railroad Ore Docks
10 = Hibbard Power Plant
11 = Sky Harbor Airport
$j = 1 - 4$
1 = Lakehead Trucking
2 = Udeen (Quad)Trucking
3 = Udeen (End − Dump)Trucking
4 = RailMate System

**Objective Function:**

$$\text{MIN:} \left( \sum_{k=1}^{TY} ( \sum_{i=1}^{11} \sum_{j=1}^{4} (CY_{ijk} \times C_{ij}) \times \left(1 + i'\right)^{k}) \right) + \sum_{k=1}^{TY} ( \sum_{i=1}^{11} \sum_{j=1}^{4} (Z_{ijk} \times C_{ij} \times D_i) \times \left(1 + i'\right)^{k}) + E + A + L$$

**Constraints**

Subject to:

$$\sum_{j=1}^{4} \sum_{i=1}^{11} CY_{ijk} + \sum_{j=1}^{4} \sum_{i=1}^{11} \left(Z_{ijk} \times D_i\right) \leq MCY_k \text{ for } k = 1, 2, \ldots, K.$$

$$\sum_{j=1}^{4} \sum_{k=1}^{K} Z_{ijk} = R_i \text{ for } i = 1, 2, \ldots 7$$

$$\sum_{i=8}^{11} \sum_{j=1}^{4} \sum_{k=1}^{K} CY_{ijk} = D_i \text{ for } i = 8, 9, 10, 11.$$

$CY_{ijk} \geq 0$

$Z_{ijk}$ binary

$$E = \left( (110 \times 10 \times 304) \times \sum N_i \times Y_i \right) + 2 \times \left( 200{,}000 \times \frac{((\sum N_i \times Y_i) \times 10 \times 304) - 3 \times 6{,}250}{12{,}500} \right)$$

$$A = (100 \times (TL_{31} + TL_{32} + TL_{33}) \times Y_1) + (1.10 \times D_6 \times Y_6) + (100 \times N_7 \times Y_7)$$

$$L = \left(1.73 \times \sum D_i \times Y_i\right)$$

# 3. Results

Implementing the models in the Excel spreadsheet and solving by the Premium Solver software, an optimal solution was found for the stage 1 model. Then the results were used partly as the input to the second stage to create the year-by-year plan. Several scenarios were generated to provide a complete analysis.

### 3.1 Scenario 1—Optimal case

This scenario uses all the assumptions mentioned in section 2.2. The overall optimal solution suggests the use of RailMate to serve two long-term customers, which are the construction fill at the CN Railroad Ore Dock and the Hibbard Power Plant, and two short-term recurring customers, being the land fill for Waste Management at Canyon and mine reclamation at UTAC. The associated costs are listed in Table 3.1.

**Table 3. 1 Scenario 1 Optimal Solution**

| Project Selected | Total Fines Removed (Cubic Yards) | Transportation Option | Transportation Costs |
|---|---|---|---|
| Waste Management (Canyon, MN) | 106,035 (in 5 years) | RailMate | $176,452.84 |
| UTAC | 44,365 (in 5 years) | RailMate | $73,827 .8 |
| CN Railroad Ore Dock | 900,000 | RailMate | $1,497,690 |
| Hibbard Power Plant | 1,000,000 | RailMate | $1,664,100 |
| Total Materials Used: 2,050,400 cubic yards | | | |
| Transportation Costs: $3,412,070.64 | | | |
| Loading and Operating Costs: $10,403,729.60 | | | |
| Equipment Costs: $1,600,000 | | Total Equipment Hours left: 12836 | |
| **Total Project Costs: $15,415,800.24** | | | |

It is expected that 90% of the fines accumulated at the pier plus the annual additions will be depleted in 21 years. During this period, Erie Pier could serve as a reuse facility since the dredged materials would be processed and recycled to serve customers' needs. It should be noted that, among the four chosen projects, CN Railroad Ore Dock and Hibbard Power Plant are less than 5 miles from Erie Pier. Rail transportation does not make sense for Waste Management at Canyon either, even though it is 30 miles from Erie Pier. For these three short-distance customers, only the road transportation part of RailMate will do the job. A truck company can also be contracted directly if the same or better unit rate (<=$17/ton) is offered. The same conclusion applies to all the following analysis in which any short-distance customers are suggested to be served by RailMate.

The year-by-year plan for the overall optimal solution suggests serving Hibbard Power Plant in years 1–12 and the CN Railroad Ore Dock in years 12–21. The amount of fines to be delivered to these two customers in each designated year can be seen in Table 3.2. The year-by-year plan for this optimal solution also suggests Erie Pier supply UTAC in the first five years to satisfy its annual demand of 8,873 cubic yards and serve Waste Management at Canyon, MN in years 1–4 and 21 to meet its annual demand of 21,207 cubic yards.

**Table 3. 2 Scenario 1 Year-by-Year Plan**

| Project Selected | Years Selected | Cubic Yards Per Year |
|---|---|---|
| Waste Management (Canyon, MN) | 1 – 4, 21 | 21,207 |
| UTAC | 1 – 5 | 8,873 |
| CN Railroad Ore Dock | 12 - 21 | Year 12: 70,807<br>Years 13-20: 100,000<br>Year 21: 29,193 |
| Hibbard Power Plant | 1 – 12 | Years 1 – 4: 69,920<br>Year 5: 91,127<br>Years 6 – 11: 100,000<br>Year 12: 29,293 |
| Total Transportation Costs (including 4% inflation & interest): $5,344,706.59 | | |

## 3.2 Scenario 2—Truck only optimal case

The calculation shows that using RailMate saves about two thirds of the transportation cost in almost every case. This explains why in the optimal scenario discussed in the previous section, all the customers are suggested to be served by the RailMate option. However, considering that RailMate is a new system not in operation yet, a second scenario was generated as a backup plan in case the RailMate option turns out to be not feasible in a short term. This scenario considers truck only as the transportation method. To identify the optimal plan in this case, the stage 1 model was modified by eliminating the RailMate option and set the j value in the models to be 1 through 3, where 1 represents Lakehead trucks, 2 represents Udeen Quad trucks, and 3 Udeen end-dump trucks.

Optimal solution in this scenario is summarized in Table 3.3. It suggests that Erie Pier should select two long-term customers, which are the construction fill for the 21$^{st}$ Ave. W. Project and at the Hibbard Power Plant. One short-term recurring customer, land fill for Wisconsin Waste Management in Superior, is also suggested. In all three cases, Udeen end-dump truck is selected as the transportation option to ship the fine materials to each customer. The transportation cost tripled but the loading and equipment cost remains to be the same and a significant part of the total cost. An additional cost is also included in this suggested solution since serving Wisconsin Waste Management in Superior requires tipping fee at $100/truck load.

**Table 3. 3 Scenario 2 Optimal Solution**

| Project Selected | Total Fines Removed (Cubic Yards) | Transportation Option | Transportation Costs |
|---|---|---|---|
| Wisconsin Waste Management | 106,035 (in 5 years) | Udeen (End-Dump) | $528,230 |
| **21st Ave. W. Project** | 950,000 | Udeen (End-Dump) | $4,039,020 |
| **Hibbard Power Plant** | 1,000,000 | Udeen (End-Dump) | $4,617,400 |
| Total Materials Used: 2,056,035 cubic yards | | | |
| Transportation Costs: $9,184,650 | | | |
| Loading and Operating Costs: $10,432,321.59 | | | |
| Equipment Costs: $1,600,000 | | Equipment Hours left: 12494 | |
| Additional Costs (for Wisconsin Waste Management): $530,500.00 | | | |
| **Total Project Costs: $21,747,471.59** | | | |

Running the stage-2 model based on this optimal solution, the optimal year-by-year transportation plan is generated with the objective to minimize the total present value of the total cost, assuming 4% inflation plus interest. Table 3.4 summarizes the results. It is suggested that Wisconsin Waste Management should be served in the first five years to meet its recurring annual demand, Hibbard Power Plant be served in years 1 through 12, and 21st Ave. W. project in years 12 to 21 with the specified amount of fine materials. When the inflation and interest is considered in calculating the transportation cost, it increases from $9,184,650 to $14,269,867.88.

**Table 3. 4 Scenario 2 Year-by-Year Plan**

| Project Selected | Years Selected | Cubic Yards Per Year |
|---|---|---|
| Wisconsin Waste Management | 1 – 5 | 21,207 |
| 21st Ave. W. Project | 12 – 21 | Year 12: 93,965<br>Years 13 – 20: 100,000<br>Year 21: 56,035 |
| Hibbard Power Plant | 1 – 12 | Years 1 – 5: 78,793<br>Years 6 – 11: 100,000<br>Year 12: 6,035 |
| **Total Transportation Costs (including 4% inflation & interest): $14,269,867.88** | | |

### 3.3 Scenarios 3 and 4 — Relaxing the "100,000 maximum removable fines per year" constraint

In the previous two scenarios, there is an assumption being that at most 100,000 cubic feet of fine materials can be removed from the pier. To test the sensitivity of the model results to this constraint, it is removed in the third scenario. In this case, the variable MCY in stage-1 model is set to be constrained by the loading capacity at the pier instead of equal to 100,000. With the assumption of 304 working days, 10 hour per day, 0.5 hours to load a truck or RailMate trailer with one loader, and about 22 cubic yard per truck or trailer load, the maximum amount of fines can be removed is 133,760 cubic yards

(MCY=$22\,\frac{yd^3}{load}\times 2\,\frac{load}{hour}\times 304\,\frac{days}{year}\times 10\,\frac{hours}{day}=133760\ yd^3/year$). It is also assumed that only one bulldozer and loader is used each time in material gathering and loading. The optimal solution under these conditions is summarized in Table 3.5.

**Table 3. 5 Scenario 3 Optimal Solution**

| Project Selected | Total Fines Removed (Cubic Yards) | Transportation Option | Transportation Costs |
|---|---|---|---|
| **21st Ave. W. Project** | 950,000 | RailMate | $1,580,895 |
| **CN Railroad Ore Dock** | 900,000 | RailMate | $1,497,690 |
| Total Materials Used: 1,850,000 cubic yards | | | |
| Transportation Costs: $3,078,585 | | | |
| Loading and Operating Costs: $7,825,500 | | | |
| Equipment Costs: $800,000 | Total Equipment Hours Left: 3410 | | |
| **Total Project Costs: $11,704,085** | | | |

It takes 14 years to remove at least 90% of the accumulated and recurring fine materials at the pier and turn it into a reuse facility in this case. The total project cost decreased as compared to the total project in scenario 1. Savings are acquired from the reduced transportation cost and equipment cost since only 2 new bulldozers and 2 loaders are needed in 14 years.

If three loaders can be used at the same time to load the fines without interfering with one another, the total cost can be decreased even more. In this case, the maximum amount of fines that can be removed from the pier is 401,280 cubic yards (MCY=$22\,\frac{yd^3}{load}\times 3\times 2\,\frac{load}{hour}\times 304\,\frac{days}{year}\times 10\,\frac{hours}{day}=401280\ yd^3/year$). It will only take 4 years to remove 1,294,365 cubic yards of fines and turn the pier into a reuse facility. In this case, no new equipment will be required and the total transportation cost is $3,677,727.80, slightly increased from $3,078,585 in the previous scenario. But the total project cost which includes the transportation cost, equipment operating cost, and loading cost decreased to $7,143,500.08. The optimal solution in this scenario suggests serving one short-term customer Keetac or UTAC for five years to meet its annual demand of 44,365 cubic yards, and two long-term customers Hibbard Power Plant and Sky Harbor Airport. It should be noted that since the annual demands of Keetac and UTAC are the same, and RailMate charges a $17/ton rate regardless of travel distance, the transportation costs calculated for these two customers are the same. However, Keetac is approximately 45 miles farther than UTAC from Erie Pier. For Keetac or UTAC and Hibbard Power Plant, RailMate is suggested as the transportation method and Sky Harbor Airport should be served by the Udeen end-dump trucks. Table 3.6 summarizes the optimal solution in scenario 4.

**Table 3. 6 Scenario 4 Optimal Solution**

| Project Selected | Total Fines Removed (Cubic Yards) | Transportation Option | Transportation Costs |
|---|---|---|---|
| Keetac or UTAC | 44,365 (recur 5 years) | RailMate | $73,827.80 |
| Hibbard Power Plant | 900,000 | RailMate | $1,664,100 |
| Sky Harbor Airport | 950,000 | Udeen End-Dump Trucking | $1,939,800 |
| Total Materials Used: 1,294,365 cubic yards | | | |
| Transportation Costs: $ 3,677,727.80 | | | |
| Loading and Operating Costs: $3,465,772.28 | | | |
| Equipment Costs: $0 | | Equipment Hours left: 15200 | |
| **Total Project Costs: $7, 143, 500.08** | | | |

*Assuming three loaders working at the same time.

### 3.4 Scenario 5 — Assuming 200 accessible days per year

Another scenario that changes the assumption of 304 working days to 200 days was looked at. This creates no problem for most customers except for Waste Management at Canyon which has been accepting 70 tons (58.1 cubic yards) of landfill materials per day. Since the annual demand of Waste Management at Canyon is around 21,207 cubic yards, only being able to remove fines from Erie Pier for 200 days per year requires Waste Management at Canyon to accept about 106 cubic yards of fines per day, which requires double processing capability. Under this condition, both scenarios of using one loader a time to load the fine materials to trucks and RailMate trailers or using three loaders at the same time are analyzed. Without three loaders working simultaneously, the project needs 32.4 years to deplete 90% of accumulated and recurring fines. On the other hand, if three loaders can work in parallel and load the materials simultaneously, it only needs 16.7 years to deplete 90% of fines. In this case, the maximum amount of fines that can be removed from the pier is 264,000 cubic yards ( $MCY=22\frac{yd^3}{load}\times3\times2\frac{load}{hour}\times200\frac{days}{year}\times10\frac{hours}{day}=264000\ yd^3/year$ ). Therefore, the model was run assuming three loaders working at the same time. The optimal solution to this second case is summarized in Table 3.7.

**Table 3. 7 Scenario 5 Optimal Solution**

| Project Selected | Total Fines Removed (Cubic Yards) | Transportation Option | Transportation Costs |
|---|---|---|---|
| **Keetac** | 106,476 (in 12 years) | RailMate | $177,186.71 |
| **UTAC** | 106,476 (in 12 years) | RailMate | $177,186.71 |
| **21st Ave. W. Project** | 950,000 | RailMate | $1,580,895 |
| **CN Railroad Ore Dock** | 900,000 | RailMate | $1,497,690 |
| Total Materials Used: 2,062,952 cubic yards | | | |
| Transportation Costs: $3,432,958.43 | | | |
| Loading and Operating Costs: $7,240,093.63 | | | |
| Equipment Costs: $2,400,000 | Equipment Hours left: 120752 | | |
| **Total Project Costs: $13,073,052.05** | | | |

*Assuming three loaders working at the same time.

Two short-term projects, Keetac and UTAC are selected to be served by RailMate for 12 years to meet their annual demand of 106,476 cubic yards. Two long-term projects, the 21st Ave W. wetland habitat project and CN Railroad Ore Dock, are selected to be served by RailMate. Six bulldozers and 6 loaders need to be purchased during the project period since three pairs of bulldozers and loaders are assumed to be used at the same time. However, 60,376 hours will be left for both bulldozers and loaders when the project completes and the equipments can continue to load the dredged materials in several following years.

Since the modified assumptions in this scenario were suggested in the dredging subcommittee meeting on Nov 17th, 2009, this scenario is regarded as relatively more important. Therefore, the optimal year-by-year plan for this scenario was generated, as shown in Table 3.8.

**Table 3. 8 Scenario 5 Year-by-Year Plan**

| Project Selected | Years Selected | Cubic Yards Per Year |
|---|---|---|
| Keetac | 1 – 10, 13, 17 | 8,873 |
| UTAC | 1 – 12 | 8,873 |
| 21st Ave. W. Project | 1 – 4 | Years 1 – 3: 246,254<br>Year 4: 211,238 |
| CN Railroad Ore Dock | 4– 17 | Year 4: 35,016 Year 5: 246,254<br>Year 6: 212,254, Years 7 – 10: 32,254<br>Years 11 – 13: 41,127 Years 14 –16: 50,000<br>Year 17: 4,079 |
| **Total Transportation Costs (including 4% inflation & interest): $4,315,542.15** | | |

## 3.5 Scenario 6 — Assuming 200 accessible days per year and truck only

The last scenario removes RailMate from scenario 5's model to identify an optimal solution when only trucks are considered as possible transportation options. Table 3.9 summarizes the optimal solution for this case. The annual demand of Wisconsin Waste Management in Superior is suggested to be served for 12 years by Udeen end-dump trucks. Two long projects, 21st Ave. W project and CN Railroad Ore Dock project, are suggested to be served also by Udeen end-dump trucks. The transportation cost is again about three fold as compared to the previous scenario. In total, 19 years will be needed to complete the project and turn Erie Pier into a reuse facility. Same number of bulldozers and loaders will be needed and the equipment hours left are similar to the previous case.

**Table 3. 9 Scenario 6 Optimal Solution**

| Project Selected | Total Fines Removed (Cubic Yards) | Transportation Option | Transportation Costs |
|---|---|---|---|
| Wisconsin Waste Management | 254,484 (in 12 years) | Udeen (End-Dump) Trucking | $1,267,752 |
| 21st Ave. W. Project | 950,000 | Udeen (End-Dump) Trucking | $4,039,020 |
| CN Railroad Ore Dock | 900,000 | Udeen (End-Dump) Trucking | $4,089,600 |
| Total Materials Used: 2,104,484 cubic yards | | | |
| Transportation Costs: $9,396,372 | | | |
| Loading and Operating Costs: $7,727,264 | | | |
| Equipment Costs: $2,400,000 | | Equipment Hours left:113200 hrs | |
| **Total Project Costs: $20,796,836** | | | |

*Assuming three loaders working at the same time.

# 4. Discussions

The assumption about the maximum amount of fine materials that can be removed yearly is a critical factor. It determines the length of the project needed to remove the accumulated and recurring material at the pier and turn Erie Pier into a re-use facility. Depending on issues such as the number of days that Erie Pier can be accessed, the speed at which the dredged materials can be loaded into trucks or RailMate trailers, the time it takes to transport the fines to each customer, and the daily capacity of customers to accept the materials, the number of years required to turn Erie Pier into a re-use facility varies. This in turn affects the number of bulldozers and loaders need to be purchased.

It is assumed that loading and unloading one truck or a RailMate trailer requires half an hour, using one loader and one bulldozer. This assumption is a conservative estimate. Depending on the loader's bucket capacity, which is usually 4 to 8 cubic yards, the amount of materials that can be loaded and transported each day differs. A time study at the pier may need to be performed to get a more accurate estimate. A bulldozer is assumed to be needed to pair with a loader to complete the gathering and loading activity. In three cases, scenarios 4 to 6, where three loaders are assumed to be working in parallel, each of the three bulldozers are also assumed to be paired with its loader to complete the material gathering job. If one bulldozer can move and gather the materials fast enough to keep up with the three loaders, the loading equipment cost can be further saved in scenarios 5 and 6: only two instead of five new bulldozers are needed in addition to the three at the pier and the savings will be $600,000.

It is assumed that all the customers except for Waste Management at Canyon are able to accept the amount of fine materials loaded by three loaders and transported in a 10-hour day. Having more information on the daily accepting capability on the customers' side will help improve the accuracy of the model. This also helps determine how sensitive the optimal solution is to the number of accessible days to Erie Pier. In addition, the planning horizons of the long-term projects are not known. Having accurate information on the time frames of the long-term projects is necessary to arrange the optimal transportation plans, especially the year-by-year plan. If the yearly demands of the fine materials for the long-term projects are evenly distributed or needs to meet specific number in different years, then the model also needs to be modified.

Table 4.1 summarizes the scenarios analyzed in this report.

**Table 4. 1 Summary of the Six Scenarios Discussed**

| Scenarios | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **Assumptions Different from the Basic Ones*** | 1. Truck only, no RailMate option is included<br>2. No upper bound on the annul removable fines<br>3. 3 loaders loading simultaneously<br>4. 200 working days per | | | | | |
| **Assumptions** | | 1 | 2 | 2 & 3 | 2, 3 & 4 | 1, 2, 3 & 4 |
| **# of years to complete project** | 21 | 21 | 14 | 4 | 17 | 19 |
| **Transportation cost** | \$3,412,071 | \$9,184,650 | \$3,078,585 | \$3,677,728 | \$3,432,958 | \$9,396,372 |
| **Loading and operating cost** | \$10,403,730 | \$10,432,322 | \$7,825,500 | \$3,465,772 | \$7,240,094 | \$7,727,264 |
| **Equipment cost** | \$1,594,629 | \$1,600,111 | \$945,455 | \$0 | \$2,400,000 | \$2,400,000 |
| **Total project cost** | \$15,410,429 | \$21,747,582 (including additional costs) | \$11,704,085 | \$7,143,500 | \$13,073,052 | \$20,796,836 |
| **Customers selected** | Waste Management in Canyon, UTAC, CN Railroad Ore Dock, Hibbard Power Plant | Wisconsin Waste Management, 21st Ave. W. Project, Hibbard Power Plant | 21st Ave. W. Project, CN Railroad Ore Dock | Keetac or UTAC, Hibbard Power Plant, Sky Harbor Airport | Keetac, UTAC, 21st Ave. W. Project, CN Railroad Ore Dock | Wisconsin Waste Management, 21st Ave. W. Project, CN Railroad Ore Dock |
| **Total amount of fines used** | 2,050,400 $ft^3$ | 2,056,035 $ft^3$ | 1,850,000 $ft^3$ | 1,294,365 $ft^3$ | 2,062,952 $ft^3$ | 2,104,484 $ft^3$ |

*Basic assumptions are discussed in Section 2.2.

# 5. Conclusions

RailMate is suggested as the desired transportation option in all cases because of its low unit transportation cost. There are several scenarios that include short-distance customers in the optimal solution and suggest RailMate as the optimal transportation solution. In these cases, only the road transportation part of RailMate will be adequate to perform the job. Erie Pier can also contract truck companies to transport the materials if the same or better unit rate (<=$17/ton) can be achieved. To serve the four long-distance customers, Floodwood Farming, Keewatin Taconite, United Taconite, and Waste Management at Elk River, RailMate is the optimal solution. Currently, there are five RailMate units available for demonstration purposes. To use RailMate to serve the selected long-distance customers, more units need to be manufactured. It has been estimated that 4.5 month lead time will be needed from receipt of an order and down payment to the delivery of RailMate equipment components. Then two complete RailMate units can be assembled per week. Based on current assumption of loading speed for the fine materials at the pier, twenty to sixty RailMate trailers can be loaded per day, depending on how many loaders can load the trailers at the same time.

In all the scenarios analyzed, the total project cost is lower than the cost to build a new CDF estimated by the USACE. This further justifies the efforts to turn Erie Pier into a re-use facility instead of building new CDF's financially. In addition, since the loading, operating and equipment cost represents a significant part of the total cost, future research can investigate the possibility to build an automatic transition station to handle the materials. Economic analysis can help reveal if further savings can be achieved by replacing the bulldozers, loaders and operating workers with an automatic or semi-automatic transition station.