Design of a Low Impact Canoe Portage System for the Hirundo Wildlife Refuge

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DESIGN OF A LOW IMPACT CANOE PORTAGE SYSTEM FOR THE HIRUNDO WILDLIFE REFUGE

by

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A Thesis Submitted in Fulfillment
of the Requirements for a Degree with Honors
(Mechanical Engineering)

The Honors College

University of Maine

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Abstract

The Hirundo Wildlife Refuge has requested a canoe portage system to be built. Before the system can be built, it is necessary to research the different designs that Hirundo can pursue. In this document, three different routes that Hirundo can pursue are designed. In order to decide what route is the best route, Hirundo requested that each route fit certain design criteria, which are also shown in the document. This thesis concludes with a recommendation for Hirundo of which design to pursue.
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Chapter 1: Introduction

1.1 Motivation:

The client is the Hirundo Wildlife Refuge (referred to as “The Refuge” from this point on). The Refuge was originally a 3-acre camp. In 1965, Oliver Larouche expanded The Refuge to its current 2,460-acre size. In 1983, the deed was given to the University of Maine, cementing a long-term collaboration. Figure 1 shows an overview of the Hirundo Wildlife Refuge. The Refuge is a nature preserve that spans Pushaw Lake and Dead Stream. The Refuge offers visitors the opportunity to use canoes and kayaks free of charge in order for visitors to explore the natural environment. The canoes and kayaks are stored in The Refuge’s visitor check in building. In addition to allowing visitors, the Refuge allows the University of Maine to perform research on the wildlife ecology of the area, such as characterizing the trees. The Refuge is best known for its involvement in past archeology research, such as teaching students how to systematically excavate an archaeological site.
The canoes of interest in this work were a gift from the Penobscot River Keepers and are a big attraction for the Refuge, making accessibility to the canoes a top priority for The Refuge. The canoes are 27 feet long and weigh nearly 300 pounds. When discussing the project, The Refuge requested a portage system that allows smaller groups of people to transport the canoes from the canoe storage to the water, which is a 150 feet distance. The Refuge requested a canoe portage system that balances three distinct variables: environmental impact, budget, and accessibility. These canoes resemble Native American war canoes, which can seat over 20 adults. An image of the canoes is shown in Figure 2. In order to use the canoes, the Refuge requires a large number of students or at least 6 grown adults to be able to move the canoes. The Refuge believes that if the canoes are more accessible to smaller groups of people that the canoes will attract more visitors. The trail section that leads to the water is a dirt trail about 150 feet in length with exposed roots and rocks.
1.2 Scope:

Currently, The Refuge requires groups of 6-8 adults or an entire classroom of children in order to move the canoes. There is no existing canoe portage system other than people power. With smaller groups, the canoes are unable to be used because of the size and weight of the canoes.

To adhere to the client’s request, potential solutions for the canoe to cross through the trail need to be designed and evaluated in order to decide which option The Refuge should pursue. To give The Refuge some options, two different potential designs were designed and compared via a scoring matrix. Option 1 is to build a bridge with a pulley system near the canoe storage area. Option 1 runs alongside the existing trail. Option 2 is adding geotextiles to the existing trail, and smoothing out the ground surface. The areas of the two options are shown in Figure 3.
1.3 Project Overview:

Because The Refuge has had an issue attracting local community members, they need to find a way to move the canoes easily to attract more groups. The portage system will help users move the canoes with greater ease. This thesis proposes 2 feasible designs and compares how well each design maintains a low cost, adheres to environmental regulations, and helps the users move the canoes. The most important criterion for The Refuge is to maintain a low cost. Environmental impact is the second most important criteria and will be discussed later. Also, aesthetics will play a role in the Refuge’s decision about which option to choose. To help the Refuge with their decision, a scoring matrix with a rubric was made for each of the categories to allow for easy comparison. Also, a recommendation was made to the Refuge’s Board in this document. The biggest
uncertainties are the permits and the allotted budget for the proposed project. The Refuge will be in charge of obtaining the permits required to utilize any of the options.

1.4 Proposed Work

1.4.1 Option 1- The Bridge

There is an existing area that a path could be cleared for a bridge to be built on. The bridge requires concrete posts to be placed in the ground to support the bridge. The environmental impacts of adding a structure in this area must be investigated. There are permitting requirements and restrictions for building near the shoreline of Pushaw River that must be considered. A cost estimate for this option was developed for assessing the viability of this approach.

1.4.2 Option 2- Using a Geotextile to level out the Trail

The existing trail can be manipulated by adding a geotextile to make the ground surface level. A geotextile helps prevent the trail from deforming under extreme loads. Before the geotextile is added, any roots and stones need to be removed to allow for the geotextile to provide a smooth pathway. The geotextile option has the potential to be invasive by causing pools of water to form on the trail, and with the removal of roots, further disturbs the area. However, the Refuge has already placed geotextiles within a different trail to a handicap accessible trail with satisfactory results. For this option, there are permitting requirements and restrictions of altering pre-existing trails near the shoreline of the Pushaw River that must be investigated.

1.5 Project Implementation
The manner in which each route will be compared is shown in Table 1. The Board of Trustees for the Refuge do not have a significant engineering background and are seeking engineering expertise and a distillation of all analyses in an easy to comprehend manner that will facilitate decision making. After the research for each route is shown to the board, they will decide which project they wish to pursue.

Table 1 - The Proposed Work for the Project

<table>
<thead>
<tr>
<th>Proposed Work</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permits</td>
<td>Research needs to be performed on the required permits needed for each project</td>
</tr>
<tr>
<td>Calculations</td>
<td>Prior to design, safety calculations for each project need to be performed</td>
</tr>
<tr>
<td>CAD Drawings of Project Components</td>
<td>A cart, a pulley system, and a bridge all need to be designing in Solidworks</td>
</tr>
<tr>
<td>Budget Estimation</td>
<td>A budget will be made for each of the projects</td>
</tr>
<tr>
<td>Matrix of Selection Criteria</td>
<td>A matrix ranking each project based on the requirements needs to be created</td>
</tr>
<tr>
<td>Present to the Hirundo Board</td>
<td>The projects need to be presented to the Hirundo Wildlife Refuge Committee</td>
</tr>
</tbody>
</table>

1.6 Restrictions

There are several restrictions to be aware of for all three design options. These restrictions are obtained through the Land Use Orono Land Code [1]. Orono Code supersedes most regulations, therefore the Orono Code is detailed first. All of the projects need to follow these restrictions in order to be allowed to be built. The Refuge will need to request permits to build the bridge, remove any section of the trail, or to add any
material to the trail.

1.6.1 Orono Code

1.6.1.1 CD18:82 Supp. No. 10

Earth-moving activities by The Refuge for the purposes of construction of public utilities or trails requires a building permit. Any Earth-moving activities associated with a business that is already in existence, such as adding gravel, will require a permit.

1.6.2 State Land Code

This section of the restrictions come from the state land code. In addition to the Orono land ordinance, the state land ordinances must be followed.

1.6.2.1: Sec. 18-130. Excavation, removal and filling of lands.

Any earth-moving activity that can cause erosion, sedimentation, or any other process that could significantly affect the water quality or the lives of aquatic creatures is prohibited. All earth-moving activities need to maintain the practices described in “Maine Erosion and Sediment Control Best Management Practices,” published by the Maine Department of Environmental Protection. Since The Refuge is subject to the Maine Stormwater Management Law, The Refuge needs to adhere to the Maine Department of Environmental Protection’s general permit for construction activity and will comply to the standards of the Maine Pollutant Discharge Elimination System. The only earth-moving activity that does not require a permit is or approval from the Planning Board is removal or filling of less than 20 cubic yards of material in any single calendar year.

1.6.2.2 Conservation plan
The applicant for site plan approval for the operation of an earth-moving activity shall present a conservation plan for the building of the activity and the restoration of the land to the Penobscot County Soil Conservation Service. Such plan shall include dates by which the various temporary and permanent conservation practices will be initiated, and must be approved by the before it will be considered acceptable.

1.6.2.3: Sec. 18-144. Wildlife/natural areas preservation.

Any project affecting significant wildlife or fisheries habitat, as identified in the current State of Maine Comprehensive Plan or by state or federal agencies, shall include mitigation measures aimed at minimizing the adverse impacts of development on these resources. The project needs to protect the wildlife habitat. Any construction within 100 feet of the upland edge of a wetland area will require a permit in order to do so. Any construction within 75 feet of any stream or waterway will be subject to shoreland zoning. All projects need to preserve existing vegetation by only removing vegetation that is necessary for the actual construction. The vegetation that will need to be removed will need to be discussed in the development plan. In order to minimize any potential noise disturbance caused by construction, planting of additional vegetation may need to be done. Erosion control practices will need to be applied to the project to ensure proper care of the shoreline.

Chapter 2: The Bridge

2.1 Overview

A 150-foot bridge is designed to start in front of the canoe storage area and will extend to the waterfront, which is about 150 feet from the canoe storage area. The bridge will be
five feet wide and will be placed over a wetland. The bridge will require concrete posts placed into the ground to prevent the bridge from sinking into the ground. Shown in the Public Utility Commision[3], the frost depth in zone 2 in the state of maine is 5 feet. This means that the concrete post needs to be driven into the ground a minimum of 5 feet before it can be considered stationary. The bridge will need to be able to safely support the cart, canoe, and two-three people. The design calculation uses the average weight of four grown males, which is 720 lbs combined. The bridge will use a winch mechanism to help guide the canoes (shown in Figure 4). The winch chosen has the capacity of 3500 lbs. Since winches do not support a weight, the winch route will still require two people to move the cart up and down the bridge. The bridge design is based on a US Agriculture Forest Services Foot Bridge, shown in Figure 5. An example of the area that needs to be cleared for the bridge is shown in Figure 6 and the area where the bridge will end is shown in Figure 7.

![Figure 4: The winch that was created by adding the winch to a spool to guide the canoes](image-url)
Figure 5: The bridge from the United States of Agriculture Forest Services that the Refuge’s bridge will be modeled after. This is just a proxy bridge and will not be used for actual construction. This bridge is found in Trail Bridge Catalog [4].

Figure 6: The area where the bridge will be built. The area in the white box shows the area that will need to be cleaned. This area is located in front of the canoe storage area, which is in Figure 3.
2.2 Design Calculations

The bridge will be built in 9 16 feet long sections with cross-sectional dimensions of 4 inch x 8 feet, shown in Figures 8 and 9 respectively. The sections are 16 feet long to ensure that the bridge is properly supported by the post. The design of the bridge is a modified version of the footbridge shown in Figure 5. Two different load cases need to be considered. The first case that needs to be assessed is the bridge with two people pushing the cart. This route is cheaper than adding the winch route. The second route consists of a single winch attached to move the cart and one person to make sure the cart moves along the bridge correctly. The bridge was broken into sections as each section's reaction forces and stresses can be calculated exactly the same assuming symmetry from the surrounding segments. The diagrams for the shear force and the moment were made by
SkyCiv.com[5]. The boundary conditions for both bridge cases are shown in Figure 10.

![Figure 8: The side view of the bridge section](image)

![Figure 9: The cross section of the bridge.](image)

![Figure 10: The boundary conditions for the bridge calculations is a combination of two different load cases, one of a point load and one of a distributed load.](image)

2.2.1 Case 1- No Winches

First, the distributed load of the weight of the bridge needs to be calculated. The
distributed load of the bridge was determined as the sum of the weight of the planks used to build the section of the bridge distributed over the total length of the bridge section.

The 2 inch x 6 inch x 8 feet planks weight 22.2 pounds each and the 2 inch x 8 inch x 16 feet weight 58.5 pounds, both planks are obtained from Home Depot [6]. The point load of Case 1 are caused by the cart and the four people that will be required to push the cart, while the cart’s weight consists of the cart’s weight plus the canoe. The weight used for the four people is the national average weight of a full grown male, which is 180 lbs per person. The average weight of males is used instead of females because on average, males are heavier than females. The free body diagram (FBD) for Case 1 is shown in Figure 11.

With the FBD, the reaction forces are found using summation of forces and moments.

\[ \sum F = 0 = R_1 + R_2 - P - W \]  

Equation 1.2
\[ \sum M_{R_1} = 0 = ((P + W) \cdot \frac{l}{2}) \cdot -R_2 \cdot l \quad \text{Equation 1.3} \]

In order to find the reaction forces and moments, it is necessary to sum up all the forces, \( \sum F \), as well as the moments about one of the fixed locations, \( \sum M_{R_1} \). Both the forces and the moments of the bridge should sum to zero to achieve static equilibrium. \( W \) is the point load of the cart and the four average size adults in the middle of the bridge.

Simplifying Equation 1.2 and substituting it into Equation 1.3 will give the reactions of the two fixed points, \( R_{1,2} \).

\[ \sum M_{R_1} = 0 = (1600 \text{ lb} \cdot \frac{16}{2} \text{ ft}) - R_2 \text{ lb} \cdot 16 \text{ ft} \]

\( R_2 = 1506 \text{ lb} \)

The reaction forces and moments are shown in a free body diagram in Figure 12.

\[ \text{Figure 12: The FBD with the reaction moments, reaction forces, and loads} \]

The shear force diagram and the bending moment diagram can be made from these values, shown in Figure 13 and 14, respectively.
After, the reactions were found, the peak stresses were determined. The primary interest is the maximum bending stress. The bending stress is found in order to calculate the factor of safety. The maximum bending stress occurs at the fixed locations shows the
maximum bending stress is shown in Equation 1.5.

\[ I = \frac{1}{12} * b * h^3 \]

Equation 1.4

\[ \sigma_{\text{max}} = \frac{M_{\text{max}} * c}{I} \]

Equation 1.5

In Equation 1.5, the \( \sigma_{\text{max}} \) is the maximum induced bending stress which is caused by the maximum bending moment, \( M_{\text{max}} \), and \( c \) is the distance the stress is to be calculated from the bridge deck’s neutral axis, shown in Figure 15. The area moment of inertia, \( I \), is found by treating the bridge’s cross section as a single element. The moment of inertia is calculated using the base of the cross section, \( b \), and the thickness of the cross section, \( h \).

The treatment of the bridge section as a single entity is performed to simplify the calculations. The cross-section is shown in Figure 9. Using the cross-sectional dimensions, the area moment of inertia and maximum bending stress is found.

\[ c = 2 \text{ in} \]

\[ l = \frac{1}{12} * (8 \times 12 \text{ in}) * 4^3 \text{ in}^3 = 512 \text{ in}^4 \]

\[ \sigma_{\text{max}} = \frac{60992.4 \text{ lb - in} * 2 \text{ in}}{512 \text{ in}^4} = 238.25 \text{ psi} \]
To complete the strength check, the maximum shear stress is calculated. The bridge is treated as a regular rectangular cross-section because all of the beams are connected. As such, the maximum shear stress, $\tau_{max}$, is determined as

$$\tau_{max} = \frac{3 + V}{2 + A}$$  \hspace{1cm} \text{Equation 1.6}$$

To find the maximum induced shear stress it is necessary to use the shear force, V, and the cross-sectional area of the bridge.

$$\tau_{max} = \frac{3 * 1506 \text{ lb}}{2 * (4 * 8 * 12 \text{ in}^2)} = 5.88 \text{ psi}$$

With the maximum stress obtained, the factor of safety for the bending stress, FS, can now be found.

$$FS = \frac{\sigma_{limit}}{\sigma_{max}}$$  \hspace{1cm} \text{Equation 1.7}$$

For a factor of safety, the maximum stress allowed for the bridge material, $\sigma_{limit}$, must be identified. The maximum allowed stress is found in Engineering Manufacturing Solutions document for bridge’s wood material [7]. The factor of safety in bending using this allowable stress yields

$$FS = \frac{1400 \text{ psi}}{238.25 \text{ psi}} = 5.9$$

A factor of safety for the shear stress can now be calculated. The maximum allowed shear stress is found in Manufacturing solutions document [7]. The factor of safety for shear is

$$FS = \frac{\tau_{limit}}{\tau_{max}}$$

Equation 1.8
\[ FS = \frac{90 \text{ psi}}{5.88 \text{ psi}} = 15.3 \]

The true factor of safety for the unloaded bridge is 5.9 since the bending stress will reach its maximum before the shear stress.

Next, the maximum beam deflection can be found. To find the beam deflection, an equation shown in the Engineering Edge document [8] was used. Every plank in the bridge has the same Modulus of Elasticity, \( E \). Delta, \( \Delta \), is the maximum deflection at the center of the bridge.

\[
\Delta = \frac{w \cdot l^4}{384 \cdot E \cdot l} + \frac{F \cdot l^2}{192 \cdot E \cdot l} \quad \text{Equation 1.9}
\]

\[
\Delta = \frac{7.35 \, \text{lb} \cdot \text{in} \cdot 192^4 \, \text{in}^4}{384 \cdot 1700000 \, \text{psi} \cdot 512 \, \text{in}^4} + \frac{1600 \, \text{lb} \cdot (16 \cdot 12)^3 \, \text{in}^3}{192 \cdot 1700000 \, \text{psi} \cdot 512 \, \text{in}^4} = 0.0977 \, \text{in}
\]

The maximum deflection of the bridge section is a tenth of an inch. The Modulus of Elasticity was found in the wood properties [7]. Using the Timber Construction Manual [9], a safe deflection for a wood bridge is about 0.384 inch for a 16’ section.

2.2.2 Case 2- Winch Route

This design load case occurs when the bridge has the cart with canoe and 3 people loaded onto it. A free body diagram is shown in Figure 16. The force of the cart and the bridge are the same as Case 1. However, there is only three people on this bridge now because the winch can help with pulling the cart down the bridge.
The same equations from Case 1 are used in Case 2. The distributed load is found exactly the same way as Equation 1.1. The case needed to be checked is when the load causes the largest moment in the section, which is when the cart is in the middle of the bridge.

\[ P \text{ lb} = 88.25 \frac{\text{lb}}{\text{ft}} \times 16 \text{ ft} = 1412 \text{ lb} \]

\[ \sum F \text{ lb} = 0 = R_1 \text{ lb} + R_2 \text{ lb} - P \text{ lb} - F \text{ lb} \]
Equation 1.9

\[ \sum M_{R1} \text{ lb} - ft = 0 = (P \text{ lb} \times \frac{l}{2} \text{ ft}) - R_2 \text{ lb} \times l \text{ ft} - (F \times \frac{l}{2}) \]
Equation 1.10

The distributed load, P, and the point load of the person and cart, F, are summed together with the reaction forces, R_{1-2}, to find the total force, \( \sum F \), which must equal zero to satisfy equilibrium. The moments about fixed location 1 need to be summed together, \( \sum M_{R1} \), and must also sum to zero in order to find the reaction forces. Just like in Case 1, Equation 1.9 can be simplified and the result substituted into Equation 1.10. This yields

\[ (1412 \text{ lb} \times \frac{16}{2} \text{ ft}) - R_2 \text{ lb} \times 16 \text{ ft} - (1422 \text{ lb} \times \frac{16 \text{ ft}}{2}) = 0 \]

\[ R_2 \text{ lb} = 1417 \text{ lb} \]
The results found can then be added to a complete FBD, shown in Figure 17. After the FBD is compiled, the shear force diagram and the moment diagram can be made, shown in Figure 18 and 19 respectively.
The stresses can be found in the same manner as Case 1. Again, the maximum stress is at the fixed locations of the bridge section. Just like in Case 1, area moment of inertia, I, can be found by using the cross section of the bridge, recall Equation 1.4. The same distance from the neutral axis, c, is used for this bridge section. The bridge section is treated like a single rectangular cross section.

\[ I = \frac{1}{12} b h^3 \]

Equation 1.4

\[ c = 2 \text{ in} \]

\[ \sigma_{\text{max}} = \frac{M_{\text{max}} + c}{I} \]

Equation 1.5

The maximum induced bending stress, \( \sigma_{\text{max}} \), is related to the maximum bending moment, \( M_{\text{max}} \). Using the cross-sectional dimensions of the bridge, the moment of inertia and maximum bending stress can be found.
\[ l = \frac{1}{12} \times (8 \times 12 \text{in} \times 4^3 \text{in}^3) = 512 \text{in}^4 \]

\[ \sigma_{\text{max}} = \frac{56720.4 \text{lb} - \text{in} \times 2 \text{in}}{512 \text{in}^4} = 221.56 \text{psi} \]

Similar to the bending stress, the shear stress is found the same way as in Case 1. Again, the calculation treats the bridge section is treated as a single rectangular cross section, shown in Equation 1.7.

\[ \tau_{\text{max}} = \frac{3 \times V}{2 \times A} \]

Equation 1.6

The maximum shear stress, \( \tau_{\text{max}} \), is found by the maximum shear force, \( V \), and the cross sectional area.

\[ \tau_{\text{max}} = \frac{3 \times 1422 \text{lb}}{2 \times (4 \times 8 \times 12) \text{in}^2} = 5.54 \text{psi} \]

The factor of safety, FS, for the bending stress is computed in Equation 1.7

\[ FS = \frac{\sigma_{\text{limit}}}{\sigma_{\text{max}}} \]

Equation 1.7

The specified bending stress, \( \sigma_{\text{limit}} \), is the same as in Case 1. The maximum bending stress is found in the Manufacturing Solutions document.

\[ FS = \frac{1400 \text{psi}}{221.56 \text{psi}} = 6.3 \]

A factor of safety for the shear stress can be calculated. The shear stress limit, \( \tau_{\text{limit}} \), is the maximum allowed shear stress. The shear stress factor of safety is obtained the same was as in Case 1, using Equation 1.8.
The true factor of safety is 6.3 for the bridge section since the bending stress is the limiting factor, not the shear stress.

The deflection of the bridge under load is now obtained. To find the beam deflection, an equation from the Engineering Edge document [8] was used. However for this case, it is necessary to add the point load to the deflection equation. The deflection is found using the same equation in Case 2, using Equation 1.9.

\[
\Delta = \frac{w \cdot l^4}{384 \cdot E \cdot l} + \frac{F \cdot l^3}{192 \cdot E \cdot l}
\]

Equation 1.9

\[
\Delta = \frac{7.35 \text{ lb} \cdot 192^4 \cdot \text{in}^4}{384 \cdot 1700000 \text{ psi} \cdot 512 \cdot \text{in}^4} + \frac{1422 \text{ lb} \cdot (16 \cdot 12)^3 \cdot \text{in}^3}{192 \cdot 1700000 \text{ psi} \cdot 512 \cdot \text{in}^4} = 0.09 \text{ in}
\]

2.3 Summary of Bridge

The bridge’s biggest environmental impact is the concrete cylinders that need to be inserted into the ground for the bridge to be supported on. The cylinders will be hard to remove from the ground. Also, building a structure near the stream’s shoreline will require proper permitting. The smallest factor of safety is for the configuration foregoing a winch and is 5.3. This factor of safety was checked against normal bridge factor of safeties, which was found in the engineeringtoolbox.com to be 5-7 [10]. An estimate of
the bridge’s cost is shown in Table 2. The cost estimate for the bridge is more than the target $2,500 cost that The Refuge presently has for this project. The projected costs exceed the budget, and the estimates in Table 2 do not include the cart, which means that this route will include another 240 dollars to arrive at the total project cost. Since the items will be purchased from Home Depot, there will be no shipping cost. The materials can be stored on The Refuge site. The bridge design will cost the most money to the Refuge, making it rather difficult for them to afford because they do not have sufficient financial resources. From the Long Term Durability Test [11], the design life of the wood used to build the bridge is at least 20 years. The bridge will need to be replaced in sections. The Refuge will use volunteers to build the bridge and thus, will not spend money on a construction team.

Table 2- The Materials Cost for the Bridge Route

<table>
<thead>
<tr>
<th>Material</th>
<th>Individual Price (in USD)</th>
<th>Amount Needed for Route 1</th>
<th>Amount Needed for Route 2</th>
<th>Bridge Route 1 Cost (USD)</th>
<th>Bridge Route 2 Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4”x4”x6’ Pressure Treated Post</td>
<td>$6.37</td>
<td>22</td>
<td>22</td>
<td>$140.17</td>
<td>$140.17</td>
</tr>
<tr>
<td>2”x6”8’ Pressure Treated Wood Planks</td>
<td>$6.27</td>
<td>320</td>
<td>320</td>
<td>$2006.40</td>
<td>$2006.40</td>
</tr>
<tr>
<td>Item</td>
<td>Cost</td>
<td>Quantity</td>
<td>Cost/Item</td>
<td>Total Cost</td>
<td>Total Cost per Year</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>--------</td>
<td>----------</td>
<td>-------------</td>
<td>------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>2”x8”x16’ Pressure Treated Wood Planks</td>
<td>$18.77</td>
<td>120</td>
<td>$2252.40</td>
<td>$2252.40</td>
<td></td>
</tr>
<tr>
<td>Winches</td>
<td>$60 + $20 for shipping</td>
<td>0</td>
<td>1</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>200 ft of Cable</td>
<td>$50 + $22 for shipping</td>
<td>0</td>
<td>1</td>
<td>$0</td>
<td>$72</td>
</tr>
<tr>
<td>Spool</td>
<td>$20</td>
<td>0</td>
<td>$0</td>
<td>$0</td>
<td>$20</td>
</tr>
<tr>
<td>Cart</td>
<td>$95 + $25 for shipping</td>
<td>2</td>
<td>2</td>
<td>$240</td>
<td>$240</td>
</tr>
<tr>
<td>Concrete Form Tube (6” x 12”)</td>
<td>$16 + $25 for shipping</td>
<td>11</td>
<td>11</td>
<td>$201</td>
<td>$201</td>
</tr>
<tr>
<td>Concrete (80lbs)</td>
<td>$4.15</td>
<td>34</td>
<td>$141.1</td>
<td>$141.1</td>
<td></td>
</tr>
<tr>
<td>Adjustable Post Base</td>
<td>$12.00</td>
<td>22</td>
<td>$264</td>
<td>$264</td>
<td></td>
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<tr>
<td>Hydraulic Post Driver</td>
<td>$175.00 daily</td>
<td>2</td>
<td>2</td>
<td>$350.00</td>
<td>$350.00</td>
</tr>
<tr>
<td>Tractor Rental</td>
<td>$242.00 daily</td>
<td>2</td>
<td>2</td>
<td>$484.00</td>
<td>$484.00</td>
</tr>
<tr>
<td>Total cost</td>
<td></td>
<td></td>
<td>$6079.04</td>
<td>$6279.04</td>
<td></td>
</tr>
<tr>
<td>Total cost per year</td>
<td></td>
<td></td>
<td>$303.95</td>
<td>$313.95</td>
<td></td>
</tr>
</tbody>
</table>

**Chapter 3: The Geotextile Route**

**3.1 Overview**

There is an existing trail that is about 40 feet away from the canoe storage area. The trail is about 150 feet from the river docking area. At the bottom of the strait part of the trail, there is a tight turn for the canoes. A map of the trail supplied by The Refuge is shown in Figure 20[12].
The trail possesses an uneven terrain that has stones, roots, and fallen trees scattered on it. The trail has a modest slope that makes a 300 pound canoe plus a 74 pound cart impractical to move by hand. In order to push the cart, it will require multiple people to help get the cart up the 4% grade, but will also need multiple people to help guide the cart down the slope. The Refuge has two large rolls of geotextiles that are 15 feet wide x 150 feet long (Mirafi 140n) that were donated and could be used to provide a possible smoothed pathway for assisting with canoe transport. An example image of the geotextile is shown in Figure 21. The Marifi 140n is a geotextile fabric and will be used to wrap around stones. The stones will be obtained from The Refuge, similar to what The Refuge did when it put geotextiles in a different trail. The geotextile helps prevent deformations in the trail due to extreme loading. The trail that will be used is shown in Figure 19. Finally, the geotextile will need to be covered with either gravel or its native soil.

Figure 20: The Wabanaki Trail, which is the trail that the canoes are going to be entered into the Pushaw Stream.
3.2 Design Calculations

To verify that the Marifi 140N is a strong enough geotextile, calculations need to be made for the puncture strength to verify that the trail is safe to allow a cart-canoe system with at least 4 people to monitor the cart. The properties of the Marifi 140N is shown in Figure 22. A factor of safety of 2.0 is used because it is higher than the factor of safety utilized in a similar project described by West Hawaii Sanitary Landfill in Hawaii.gov. The Hawaii.gov example draws upon the 4th edition of the Designing with Geosynthetics 4th Edition [13]. For this thesis, the following steps are from the Designing with Geosynthetics 6th Edition [14] are replicated albeit with values specific to the Refuge’s situation. The data for the strengths of Marifi 140N is found on the Tencate Geosynthetics website [15] and verified on the Innovative Geosynthetics product description [16].
3.2.1 Puncture Resistance

The equation for the puncture strength is shown in Equation 3.1 and was obtained from the *Designing with Geosynthetics* textbook 4th edition [13].

\[
F_{\text{reqd}} \text{ lbs} = p' \text{psi} \times d_a \text{ in}^2 \times S_1 \times S_2 \times S_3 \times FS \times RF
\]

Equation 2.1

The \(F_{\text{reqd}}\) is the puncture force on the geotextile. The \(p'\) is the pressure applied by the cart and the people. \(D_a\) is the average diameter of the stones, while the \(S\)'s are shape factors. Finally, FS is the factor of safety and RF is the reduction factor.

First, the stress at the geotextile’s surface need to be calculated. The equations below are found in the example used in the *Designing with Geosynthetics* textbook 4th edition [13].

\[
p' = P_T + d \times P_{\text{dirt}}
\]

Equation 2.2

\[
p' = 90 \text{ psi} + 24 \text{ in} \times 2 \text{ lb in}^3 = 138 \text{ psi}
\]
The stress at the geotextile’s upper surface, p’, must be calculated in order to find the geotextile reserve capacity. The stress at the geotextile’s surface is dependent on the pressure from the tires, $P_T$, which is an average of 90 psi. The depth of the geotextile, $d$, times the average pressure of the dirt, $P_{dirt}$, is required because it will also be applying pressure on the geotextile.

In order to correctly find the puncture resistance, a reduction factor needs to be added to Equation 2.1. The reduction factor, $RF$, scales the burst pressure to accommodate any potential damages that can occur to the geotextile.

$$RF = RF_{ID} * RF_{CR} * RF_{CD} * RF_{BD}$$  \hspace{1cm} \text{Equation 2.3}

In this expression, $RF_{ID}$ is the installation damage assumed to be 1.15 because volunteers will be installing the geotextile in wet area where the soil is more like silt. The $RF_{CR}$ is the creep assumed to be 1.6 shown in research done by Karlsson [16]. $RF_{CD}$ is the chemical degradation, assumed to be 1 because Marafi 140N is resistive to chemical degradation. $RF_{BD}$ is the biological degradation and assumed to be 1.2 because it is inert to biological degradation.

$$RF = 1.15 * 1.6 * 1 * 1.2 = 2.208$$

The vertical force, $F_{reqd}$, is found through an equation given in the example in *Designing with Geosynthetics*. It is dependent on different factors. These factors are as follows: $S_1$ is the protrusion factor, $S_2$ is the scale factor to adjust the ASTM D4833 test, $S_3$ is the shape factor to adjust flat puncture probe of ASTM D4833 to actual shape. The factors were obtained in the research done by Karlsson [16].
\[ S_1 = \frac{h_n}{d_a} \]  
Equation 2.4

\[ S_1 = .33 \]

\[ S_2 = \frac{d_{\text{probe}}}{d_a} \]  
Equation 2.5

\[ S_2 = \frac{.315}{.75} = .42 \]

\[ S_3 = 1 - \frac{A_p}{c} \]  
Equation 2.6

\[ S_3 = .6 \]

The protrusion height, \( h_n \), is based on the diameter of the stones. The probe diameter, \( d_{\text{probe}} \), is the probe that the ASTM D4833 test uses. \( A_p/c \) is the shape factor for the material that is inside the geotextile, for rounded and relatively large pieces \( S_3 \) is .6.

\[ F_{\text{reqd}} \text{ lbs} = 138 \text{ psi} \times (1 \text{ in})^2 \times .33 \times .42 \times .6 \times 2 \times 2.208 = 50.68 \text{ lbs} \]

The minimum ultimate puncture strength needed to hold a factor of safety of 2.0 is 50.68 lbs and the Marifi 140N can handle 65 lbs. The Marifi 140N is a strong enough geotextile material to withstand the pressure applied. For this loading case, the maximum factor of safety is 2.57.

### 3.3 Results from Calculations for the Geotextile

The Marifi 140N can withstand the different loads that it will be subjected to. The factor of safety exceeds 2.0 for all scenarios investigated for the Marifi 140. Based on the Hawai.gov example [13], the chosen factor of safety of 2.0 is adequate for the proposed
3.4 Amount of Gravel needed

The primary calculation needed for the landfill route is to estimate the amount of gravel needed to fill in the trail. To accomplish this, the trail needs to be treated like a driveway. The surface area is shown in Equation 3.1

\[ Sa = L \times w \]  

\[ Sa = 150 \text{ ft} \times 5 \text{ ft} = 750 \text{ ft}^2 \]

The surface area of the trail, \( Sa \), is needed to find the volume. The area is found by multiplying the length, \( L \), and the width, \( w \), of the trail. To get the volume, the desired depth of the gravel trail needs to be multiplied to the surface area. According to a study done in Ohio State [18], the average acceptable depth of a gravel is 8 inches. With the geotextile being around 8 inches underneath the trail, an all gravel route was calculated.

\[ V = Sa \times d \]  

\[ V = 750 \text{ ft}^2 \times \frac{2}{3} \text{ ft} = 500 \text{ ft}^3 \]

The volume, \( V \), needs to be converted into cubic yards as this is the unit of measure required for ordering and purchasing gravel.
\[ V = 1950 \frac{ft^3}{27 \, yd^3} = 18.52 \, yd^3 \]

### 3.5 Summary of Geotextile Route

The geotextile is the most affordable route because the Refuge already has the geotextile material. The geotextile has the potential to be invasive because of the chance forming puddles on top of the trail. The geotextile has a flow rate of 140 gal per minute-ft². However, the Hirundo Wildlife Refuge has already placed geotextiles inside their refuge with limited repercussions to the environment. Other than the removal of rocks and roots, it will be a rather aesthetic route as the trail appearance will not change a great deal, once the geotextile is added, if the natural soil is used instead of gravel. According to the Woodland Stewardship [19], the natural soil is chosen to be placed on top of the geotextile, drainage can not occur and and hydrostatic pressures will need to be considered by using back and base drains. If gravel is used, drainage will occur easily and there will be no fear of puddles forming. However, damages to the geotextile will be greater than the natural soil route. People will be needed to dig out the trail in order to add the geotextile under the trail. Gravel is around $60 dollars for a cubic yard. Depending on how much gravel The Refuge has to spare, it could cost The Refuge upwards of $4,000 dollars, depending on where the gravel is purchased. The potential budget is shown in Table 3. The budget is only if The Refuge does not have enough gravel to fill in the geotextiles.

A truck will be needed to move a large number of rocks to the Wabanaki trail. The geotextile is beneficial to the user pushing the cart because the slope of the trail can be
made more gradual and will be significantly smoother. The geotextile is used by surrounding rocks with the geotextile material (to resemble a sausage), which will help with the drainage issues of the geotextile. However, the user will be forced to somehow turn the 27’ long canoes at the bottom of the slope and they will also have to push the cart back up the slope. All in all, the geotextile route is a solid route that cost the least amount and will last for a long time without replacement. According to research done by Tencate [20], the design life for Marifi 140N is 75 years. The gravel will need to be replaced more often than the geotextile. The geotextile will help the gravel not sink into the ground, but should be inspected yearly to ensure that the trail is still evenly covered with gravel.

Table 3- The Potential Budget for the Geotextile Route

<table>
<thead>
<tr>
<th>Material</th>
<th>Individual Price (in USD)</th>
<th>Amount Needed for Route 1</th>
<th>Amount Needed for Route 2</th>
<th>Bridge Route 1 Cost (USD)</th>
<th>Bridge Route 2 Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>$60.00 per cubic yard</td>
<td>19</td>
<td>0</td>
<td>$1140.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Dump Truck Rental</td>
<td>$950.00 per day</td>
<td>1</td>
<td>1</td>
<td>$950.00</td>
<td>$950.00</td>
</tr>
<tr>
<td>Cart</td>
<td>$95 +$25 for shipping</td>
<td>2</td>
<td>2</td>
<td>$240</td>
<td>$240</td>
</tr>
<tr>
<td>Maintenance Cost per year</td>
<td>$20.00 per square yard</td>
<td>28</td>
<td>0</td>
<td>$560</td>
<td>$0</td>
</tr>
<tr>
<td>Total cost</td>
<td></td>
<td></td>
<td></td>
<td>$2330</td>
<td>$1190</td>
</tr>
<tr>
<td>Total cost per year</td>
<td></td>
<td></td>
<td></td>
<td>$591.07</td>
<td>$15.87</td>
</tr>
</tbody>
</table>

Chapter 4: The Cart

A cart is needed for all the routes. The suitable cart was found on Northern Tool + Equipment is shown in Figure 23. The cart cost $94.99 dollars. The cart weighs only 74.0 lbs and can hold up to 1400 lbs. To ensure that the canoes will stay on the carts, ratchet
straps will be used to go around the whole cart. The dimensions of the cart are 4 feet x 2 feet. The cart will require people to walk beside it to help guide the cart, in all routes.

![Figure 23: The cart that should be purchased](image)

The biggest benefit to this cart is that its barriers can be taken down, shown in Figure 24. This is very necessary because the canoe is about 50 inches wide. The canoe will also be too long for the whole canoe to sit on a single cart, a comparison shown in Figure 25. In order to help prevent the canoe from tipping, two carts will be needed and connected to one another. They will be connected by a hook spot in the back of the cart. The handles for both carts will be removed and the wheels will need to be locked to not allow free rotation. Cradles should not be needed because the cart is wide enough to hold the canoes on it and the canoes will be ratchet strapped down to the cart.
Chapter 5: Option Assessment

To conclude this design study, the four routes of the two different options are compared to identify the design to be recommended to the Refuge. To undertake this effort, a
scoring rubric is created that rates each route on a scale from 1-3 for various criteria.

There are 4 categories and the minimum and maximum scores are 4 and 12 respectively. Table 3 shows the matrix for the point system for the categories. A lower overall score indicates a more desirable solution.

Table 4 - The Matrix for the Point System

<table>
<thead>
<tr>
<th>Cost</th>
<th>Environmental Impact</th>
<th>User Benefits</th>
<th>Aesthetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>5- The most expensive route</td>
<td>5- Adheres to environmental regulations with drainage issues</td>
<td>5- Canoes no longer need to be lifted to be moved but still has slopes to overcome</td>
<td>5- Greatly changes the looks of the Wabankai trail or surrounding area</td>
</tr>
<tr>
<td>3- About half the price of the most expensive route</td>
<td>3- Adheres to environmental regulations</td>
<td>3- Canoes no longer need to be lifted and no slopes to overcome</td>
<td>3- Changes some of the looks of the existing trail or surrounding area</td>
</tr>
<tr>
<td>1- Free</td>
<td>1- Adheres to environmental regulations and does not cause any issues</td>
<td>1 -Makes moving the cart almost effortless</td>
<td>1 -The natural look of the Wabanaki Trail is maintained</td>
</tr>
</tbody>
</table>

Table 5 shows the matrix for the total score for each route.

Table 5- The Points scored for each route
<table>
<thead>
<tr>
<th></th>
<th>Score of the Bridge with no Winch</th>
<th>Score for the Bridge with a Winch</th>
<th>Score for Geotextiles using Natural Soil</th>
<th>Score for Geotextile using Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>User Benefits</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>12</td>
<td>11</td>
<td>10</td>
</tr>
</tbody>
</table>

According to the assessment matrix, the geotextile is the most desirable as it has the lowest score. Shown in Table 4, the geotextile route is the most aesthetic route and is tied for the cheapest route because the refuge already has two rolls of geotextile material. The geotextile is also the most aesthetic route because it does not disturb the natural look of the trail. Also shown in the table, the downside of the geotextile route is the user benefits because it still depends on the users to move the cart up and down the slope. The second best score was the bridge with the winch. The bridge without the winch scored about the same as the other possible route. The bridge with the winch is the most beneficial to the user because it depends on the winch-pulley system to move the cart. However, the bridge without the winch is still more beneficial for the user because there is no slope to deal with. Another benefit is that the bridge is the most environmental friendly because there is no fear of blocking pre-existing water ways. However, the bridge with the winch will cost the most money for the Hirundo Wildlife Refuge with the bridge without the winch costing almost the same.

The final recommendation is to pursue the geotextile route as it balances out the most important criteria better than the other two routes. However, the bridge with the winch is a close second. The geotextile route will require more people power or a lot more time to set up. It will require digging out the trail deep enough for the geotextile to be placed
under the trail. The bridge will require some people power because the bridge will need its pieces to be shaped correctly and will require assembly.
Chapter 6: References


3) Public Utility Commission, § RULES FOR THE ENERGY EFFICIENCY BUILDING PERFORMANCE STANDARDS ACT. Print.


8) Edge, LLC. Engineers. "Bending, Deflection and Stress Equations Calculator for Beam Fixed at Both Ends with Uniform Loading." Engineers Edge.


Appendix A

1) The Winch
2) Bridge
About the Author

Anthony Kingston was born in San Diego, California on June 11th, 1995. His father was in the military, which forced him to move around every three to four years. He ended up going to Poway High School, which is about 30 minutes away from San Diego. After completing high school, Anthony attended the University of Maine to pursue a degree in Mechanical Engineering, as well as a minor in Mathematics. Also, Anthony is a part of the University of Maine Honors College. In his junior year, Anthony joined the Order of the Engineer.

Anthony had many different jobs throughout college. His first job on campus was a Student Lab Technician for the Crosby Laboratory. While working as a Student Lab Technician, Anthony became a Research Assistant for Michael Peterson helping in Racing Surfaces Testing. Afterwards, Anthony had a job as a Student Media Assistant for the College of Engineering. During the summer of his junior year, Anthony worked as a Quality Control Engineer for Tempus Applied Solutions. He is a candidate for the Bachelors of Science degree in Mechanical Engineering from the University of Maine in May, 2017.