NATIONAL UNIVERSITY

Bay Area Rapid Transit (BART)

Reduction of Maintenance Burden Through Stair Thread Upgrade

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Master of Science in Engineering Management

ENM 607C: Capstone C

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MASTER'S CAPSTONE PROJECT APPROVAL FORM

This capstone project paper has been submitted to the Department of Technology and Engineering, National University, in partial fulfillment of the requirements for the Master of Science in Engineering Management by:

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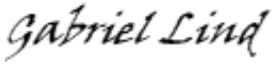

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Abstract

As large part of the public transportation network in the Bay Area, maintaining the stations of San Francisco Bay Area Rapid Transit (BART) is a costly undertaking. One of the ways to reduce the maintenance burden is to upgrade the stair threads from the current yellow thermoplastic paint to an aluminum nosing that allows for the insertion of colored rubber inserts to increase maintenance intervals while still maintaining the safety and building code requirements. In this report, we will analyze the cost-benefit of this project so that BART can serve its customers efficiently and reduce costs effectively.

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Student Bio

Derry Moten: Lives in the San Francisco Bay Area and is a San Francisco Bay Area Rapid Transit engineer. He has worked there for the last 4 years and aspires to use his degree to become a project manager.

Dennis Miller: Was in the Navy for 10 years. He worked as an Engineer doing R&D in Washington DC and recently moved to Jacksonville, FL. This degree will help him with my job search and give me more opportunities in his future career.

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1. Introduction and Project Overview

In this project, our group undertook the project management challenge of ensuring that the implementation plan of stair tread replacement within a station of the Bay Area Rapid Transit (BART) District system would meet the goals of the financial analysis through decreased maintenance. Using data gathered by BART Maintenance, our team established a set of criteria to determine the best way to rank the staircases throughout the system's passenger stations. After the location that provided the most value to the district by replacement was determined, the group produced a project initiation document. In addition to this documentation, a project schedule and budget were determined based on BART Standards, established procedures for BART project management, and previously performed BART work.

After creating the project plan, the cost forecast for stair tread replacement at the selected station and the 'do-nothing' option of standard maintenance were compared. It was determined that implementing stair tread replacement would save costs compared to the 'do nothing' option.

1.1. Project and Sponsor Background

The Bay Area Rapid Transit District (BART) is a San Francisco Bay Area public transit system that uses heavy-rail trains to service the passenger base with 131 miles of track spanning 5 Northern California counties. In 2022, over 41 million paid passengers passed through the gates of its 50 passenger stations, making it the 5th most popular heavy rail rapid transit system in the United States (American et al. Association, 2023). Overall, BART trains carry 25% of all transit miles in California. Maintaining such an extensive system has a large cost. Over the next 10 years, BART will spend $7.66B in labor expenses within its system (Bay Area Rapid Transit, 2022). During the COVID-19 pandemic, BART ridership dropped to just 6% of its pre-pandemic

levels. As of today, it has regained 40% of pre-pandemic passenger levels. Since ridership is slowly increasing, BART is looking for ways to decrease operating expenses. BART can decrease expenditures by reducing the maintenance burden of maintaining and repairing the system. One area of improvement that BART has identified is the stair tread systems within the system.

1.2. Problem Statement

The thermoplastic paint covering the nose of the stair treads in BART stations wears out too quickly for the current maintenance cycle because replacing them is expensive and time-consuming.

1.3. Key Objective

Will replacing the thermoplastic paint on the stairs with an aluminum nose covering reduce the operational cost of the stairs by 30% over 10 years?

1.4. The Scope of the Project

The main driver for operational cost is the degradation of the thermoplastic nose that covers the concrete tip of each stair. The independent variables are the number of passengers per year that use the stations, the size of the staircases, labor costs, and material costs. These variables will be used as the criteria for which staircases are chosen to refurbish to maximize the benefit of the independent variables and reduce the maintenance costs after the installation.

After the staircases are chosen, we will plan the renovation of the staircases and analyze the costs. We will complete the project initiation and construction schedule documents using BART's forms templates and process. The last phase is to create a report and presentation on our findings and present them to the University faculty and sponsor at BART by October 31, 2023.

1.5. Limitations of the Study (out of scope)

Anything not listed in Appendix A, the Letter of Engagement, as 'in scope' will be assumed to be 'out of scope' unless otherwise agreed upon. To complete this project, all the team's conclusions will be backed up by BART documentation. The team will not be responsible for soliciting bids, contracts, or other requirements to initiate the project. The deliverables of the Bill of Materials, preliminary design, and prototype are out of scope as they were not part of the agreed working charter with our sponsor.

Furthermore, meeting the project goal depends on various economic factors like inflation and cost of living wage increases over time, and the team is not responsible for predicting or forecasting these conditions for the future.

2. Methodology and Data Collection Process

2.1. SMART + Objective

Specific	Measurable	Attainable	Relevant	Time-bound
S	M	A	R	T
We will evaluate the health of the staircases and plan the renovation to minimize the operational cost of maintaining them	The project aims to reduce the operational cost of maintaining the staircases by 30% over 10 years after installation	We have estimated that this project will take us 469 days, and the calculated probability of completion is 100% by 1/13/2025	The Staircases are vital BART infrastructure, and passengers cannot use the stations without them	The project 3 phases; preparation, construction, and close out, will begin on 10/2/2023 and finish on 1/13/2025

Figure 1. Smart Objectives

The main scope of the project is the evaluation of the various staircases using documentation provided by BART by devising a scoring system to determine the condition of the staircase and plan the repair of 4 staircases to reduce the long-term maintenance costs. To tie in the various components of the project management principles that we have learned throughout our courses, we used the documentation provided by BART to include project initiation documentation, project execution plans, construction schedule (GANTT chart, WBS (Work Breakdown Schedule), etc.), budget analysis using data provided by BART. We created the documentation a BART Project Manager would provide for a project's inception.

2.2. Project Decomposition and Methodology

Our project methodology is straightforward. To determine if the staircase renovation will meet our goal of saving 30% over "doing nothing" in 10 years we first had to select a set of staircases for renovation. Then we determined the cost of doing nothing, i.e., how much money BART would be expecting to pay over the next 10 years continuing what they have been doing. After that we had to determine the cost of renovation in both material cost and labor. Finally, after we have the expected costs of both scenarios, we can compare the costs and analyze the risks to achieving our goal.

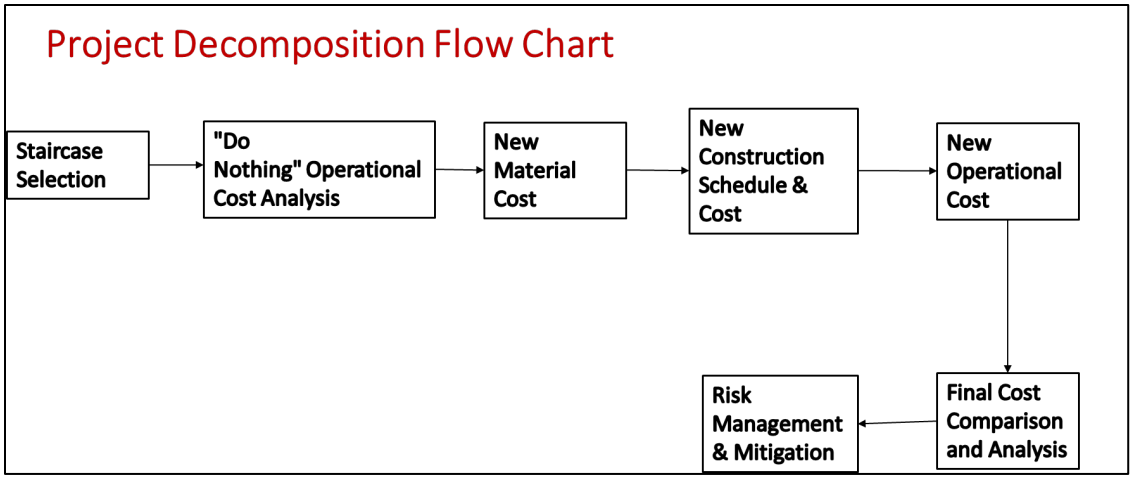

Figure 2. Project Decomposition Flow Chart

2.2.1. Staircase Selection

To select the staircases for renovation we used a Weighed Factor Scoring Method and BART's own assessments of 314 staircases in 35 stations. We chose 4 criteria: safety risk to passengers, code compliance, number of passengers per year in each station, and the number of treads.

Scores					
Criteria	**0**	**1**	**2**	**3**	**4**
Safety Risk to Passengers	None	Minimal	Elevated	High	Severe
Code Compliance	In Compliance	Minimal Remediation Required	Moderate Remediation Required	Heavy Remediation Required	OOC
Passengers Per Year	<600,000	600,001 - 1,500,000	1,500,001 - 3,000,000	3,000,001 - 5,000,000	>5,000,000
Number of Treads	5 or less	5 to 20	21 to 40	41 to 80	81+

Figure 3. Weighted Factor Scoring Criteria and Scores

For safety risk to passengers and code compliance, we got the scores directly from BART's inspection paperwork. For passengers per year and number of treads our team created the ranges for the scores based on usage and staircase information provided by BART.

We created the weights to prioritize passenger safety, code compliance, passengers per year, and number of treads in that order.

Criteria	Weights
Safety Risk to Passengers	0.45
Code Compliance	0.32
Passengers Per Year	0.16
Number of Treads	0.07
Total	**1.000**

Figure 4. Weighted Factor Scoring Criteria and Weights

After scoring all the staircases we chose the four staircases in MacArthur Station with a score of 3.02.

Location	Stair Designation	Safety risk to passengers	Code Compliance	Passengers per year	Treads	Weighted Score
K30 - MacArthur	EE1	3	4	2	1	3.02
K30 - MacArthur	EE2	3	4	2	1	3.02
K30 - MacArthur	EE3	3	4	2	1	3.02
K30 - MacArthur	EE4	3	4	2	1	3.02

Figure 5. MacArthur Station Weighted Factor Scores

See Appendix B for the scores of all the staircases.

2.2.2. "Do Nothing" Operational Cost analysis

BART's policy and maintenance records show that quarterly inspections are performed on each staircase and the thermoplastic paint is removed and reapplied every other year. From this we have calculated that for years without removal and reapplication of the thermoplastic BART spends 48 labor hours on the MacArthur Staircases (12 hours/ staircase).

On years that require the removal and reapplication of the thermoplastic paint, we have determined that BART spends 360 labor hours (90 hours/ staircase) and $300 on materials for the reapplication. This labor cost includes the quarterly inspections and Engineering Project Management hours.

"Do Nothing" (Each Staircase)								
Materials	Labor Hours (const)	Labor Hours (PM)	Labor Hours (finance)	Labor Rate (Const)	Labor Rate (PM)	Labor Rate (finance)	Overhead	Labor + Overhead
$ (300.00)	86	4		$ (121.87)	$ (194.86)	$ (157.12)	$ (1,689.04)	$ (12,949.30)
	12			$ (126.89)	$ (202.89)	$ (163.59)	$ (228.40)	$ (1,751.10)
$ (300.00)	86	4		$ (132.12)	$ (211.25)	$ (170.33)	$ (1,831.08)	$ (14,038.30)
	12			$ (137.56)	$ (219.95)	$ (177.35)	$ (247.61)	$ (1,898.36)
$ (300.00)	86	4		$ (143.23)	$ (229.01)	$ (184.66)	$ (1,985.07)	$ (15,218.89)
	12			$ (149.13)	$ (238.45)	$ (192.27)	$ (268.44)	$ (2,058.01)
$ (300.00)	86	4		$ (155.28)	$ (248.27)	$ (200.19)	$ (2,152.01)	$ (16,498.76)
	12			$ (161.67)	$ (258.50)	$ (208.43)	$ (291.01)	$ (2,231.08)
$ (300.00)	86	4		$ (168.33)	$ (269.15)	$ (217.02)	$ (2,332.99)	$ (17,886.26)
	12			$ (175.27)	$ (280.24)	$ (225.96)	$ (315.48)	$ (2,418.71)
								$ (88,448.75)
Total For All 4 Staircases								$ (353,795.01)

Figure 6. Expected 10 Year costs without replacement.

Over 10 years, we have determined that BART will spend $353,795.01 on the four MacArthur staircases if they do not undertake the project.

It is worth noting at this point that we have taken BART's historical annual increase in labor wages of 4.12% and continued that trend over the 10-year period. Also, the overhead is calculated by taking 15% of the direct labor charges.

2.2.3. New Material Cost

Rock Ridge Station	W (in)	L (in)	#	Unit Price (sq in)	Total Price
RRS E1 TOP LANDING-W95.0XL95.0	95	95	1	$ 0.87	$ 7,838.35
RRS E1 MID LANDING-W95.0XL53.0	95	53	1	$ 0.92	$ 4,649.80
RRS E1 BOT LANDING-W95.0XL95.0	95	95	1	$ 0.87	$ 7,819.93
STMB-A11 D-ECO-V3C5-BART-45.0	45	11	44	$ 0.53	$ 11,513.70
					$ 31,821.78
MacArthur (EE1)	W (in)	L (in)	#	Unit Price (sq in)	Total Price
TOP LANDING	66	24	1	$ 0.92	$ 1,457.28
MID-TOP LANDING	66	52	1	$ 0.92	$ 3,157.44
MID-BOT LANDING	54	74	1	$ 0.92	$ 3,676.32
BOT LANDING	54	24	1	$ 0.87	$ 1,127.52
STMB-BART- 54.0	54	11	24	$ 0.53	$ 7,555.68
STMB-BART- 66.0	66	11	11	$ 0.53	$ 4,232.58
					$ 19,749.54
MacArthur (EE1, EE2, EE3, EE4)					$ 78,998.16
Sales tax Oakland 10.25%					$8,097.31
			Grand Total		$87,095.47

Figure 7. New Material Costs

By examining past purchase orders from Rockridge Station and specifications of the MacArthur staircases we calculated the material cost for the new aluminum nose coverings. The aluminum nose coverings are expected for all four MacArthur staircases is $87,095.47.

2.2.4. New Construction and Operational Cost

Using BART's Estimate to complete templet and the new material costs we determined the replacement project will require 452 labor hours divided between construction, project management/ engineering, and financial work. Taking the new material cost from section 2.2.3

Funding	Q1 2024	Q2	Q3	Q4
Labor	$ 9,528.00	$ 14,987.00	$ 37,413.00	$ 10,763.87
Materials	$ 87,095.47	$ 800.00		
Total	$ 96,623.47	$ 15,787.00	$ 37,413.00	$ 10,763.87
Cumulative Total	$ 96,623.47	$ 112,410.47	$ 149,823.47	$ 160,587.34
Cumulative %	60%	70%	93%	100%

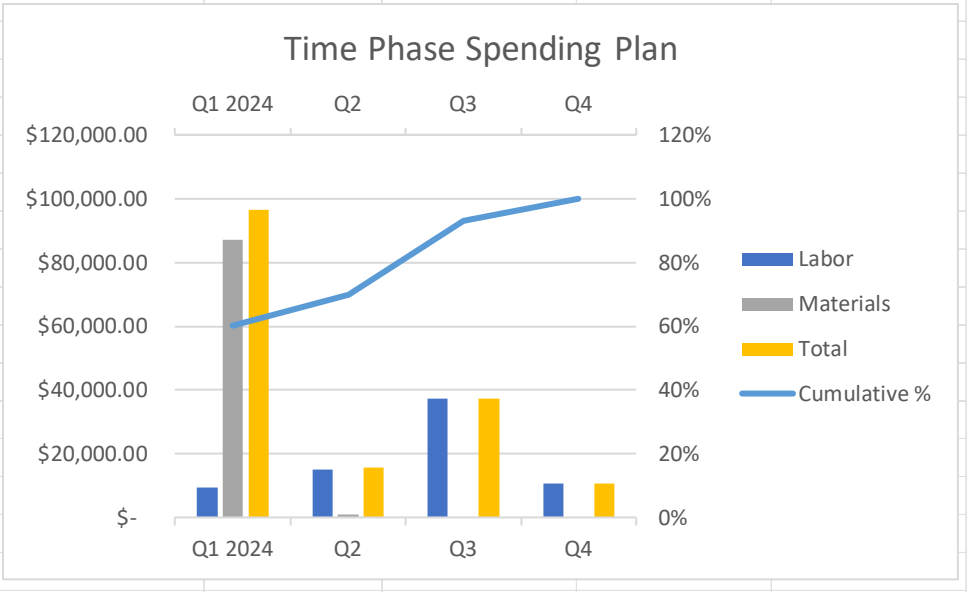

Figure 8. Construction Schedule and Costs

and adding $800 for consumable material (tape, pens, chalk, etc.) we calculated the construction will cost $160,587.34. This construction will occur in ‘year 0’ of the 10-year cost analysis.

It is standard practice for BART to include a project reserve in their project estimates for contingencies, for this project the reserve would be $48,306. We have not included the project reserve in the estimated cost in this section.

	Stair Tread Replacement								
Year	Materials	Labor Hours (const)	Labor Hours (PM)	Labor Hours (finance)	Labor Rate (Const)	Labor Rate (PM)	Labor Rate (finance)	Overhead	Labor + Overhead Cost
0	$ (87,895.47)	320	92	40	$ (121.87)	$ (194.86)	$ (157.12)	$ (9,481.55)	$ (72,691.87)
1	$ -	48			$ (126.89)	$ (202.89)	$ (163.59)	$ (913.62)	$ (7,004.39)
2	$ -	48			$ (132.12)	$ (211.25)	$ (170.33)	$ (951.26)	$ (7,292.97)
3	$ -	48			$ (137.56)	$ (219.95)	$ (177.35)	$ (990.45)	$ (7,593.44)
4	$ -	48			$ (143.23)	$ (229.01)	$ (184.66)	$ (1,031.25)	$ (7,906.29)
5	$ -	48			$ (149.13)	$ (238.45)	$ (192.27)	$ (1,073.74)	$ (8,232.03)
6	$ -	48			$ (155.28)	$ (248.27)	$ (200.19)	$ (1,117.98)	$ (8,571.18)
7	$ -	48			$ (161.67)	$ (258.50)	$ (208.43)	$ (1,164.04)	$ (8,924.32)
8	$ -	48			$ (168.33)	$ (269.15)	$ (217.02)	$ (1,212.00)	$ (9,292.00)
9	$ -	48			$ (175.27)	$ (280.24)	$ (225.96)	$ (1,261.93)	$ (9,674.83)
	Total								$ (235,078.77)

Figure 9. Stair Tread Replacement Cost Over 10 Years

After determining the new construction cost, we were able to determine the expected Operational cost over 10 years using a similar process to section 2.2.2.

We determined the total construction and operational cost for renovating the staircase over 10 years to be $225,078.77.

2.2.5. Cost Comparison and Analysis

Once we have determined the expected costs for both scenarios, we were able to compare them. A few things are very apparent when looking at the year-over-year costs associated with the scenarios side by side.

Year	Replacement	Do Nothing
0	$ (160,587.34)	$ (52,997.20)
1	$ (7,004.39)	$ (7,004.39)
2	$ (7,292.97)	$ (57,353.21)
3	$ (7,593.44)	$ (7,593.44)
4	$ (7,906.29)	$ (62,075.55)
5	$ (8,232.03)	$ (8,232.03)
6	$ (8,571.18)	$ (67,195.03)
7	$ (8,924.32)	$ (8,924.32)
8	$ (9,292.00)	$ (72,745.04)
9	$ (9,674.83)	$ (9,674.83)

Figure 10. Yearly costs of the Stair Tread Replacement and Doing Nothing

The first thing that we noticed, and was expected, was the large upfront investment in year 0 in the replacement. But what was not as obvious to us was how expensive the labor costs were expected to be for the "Do Nothing" scenario each time the thermoplastic needed to be replaced.

Then we compared the total costs over the 10-year period and can see that without considering the cost of capital, the stair tread replacement costs about $118k less over 10 years.

	Stair Tread Replacement		"Do Nothing" (Each Staircase)	
Year	Materials	Labor + Overhead Cost	Materials	Labor + Overhead
0	$ (87,895.47)	$ (72,691.87)	$ (300.00)	$ (12,949.30)
1	$ -	$ (7,004.39)		$ (1,751.10)
2	$ -	$ (7,292.97)	$ (300.00)	$ (14,038.30)
3	$ -	$ (7,593.44)		$ (1,898.36)
4	$ -	$ (7,906.29)	$ (300.00)	$ (15,218.89)
5	$ -	$ (8,232.03)		$ (2,058.01)
6	$ -	$ (8,571.18)	$ (300.00)	$ (16,498.76)
7	$ -	$ (8,924.32)		$ (2,231.08)
8	$ -	$ (9,292.00)	$ (300.00)	$ (17,886.26)
9	$ -	$ (9,674.83)		$ (2,418.71)
	Total	$ (235,078.77)		$ (88,448.75)
			Total For All 4 Staircases	$ (353,795.01)

Figure 11. Cost Comparison over 10 years

Because this project has many different costs over the course of a decade, we can compare the present values of the future costs to see the Net Present Values of each scenario. Using the yearly costs in Figure 9 and a discount rate of 1.90% we see cost savings of 30% over 10 years.

Net Present Value		Replacement	Do Nothing
Discount Rate	1.90%	($223,872.12)	($319,856.62)
Cost Benefit Over 10 Years	($95,984.49)		
avings over 10 Years	30.01%		

Figure 12. Net Present Value Comparison with 1.90% discount rate

2.3. Risks Related to the Analysis

New construction material costs, BART employees' wages (the cost of labor), and the discount rate for the net present value analysis are the 3 factors that pose the biggest risk to the accuracy of our analysis.

To reduce these risks, we have used the most current available data from BART to determine two of these factors, new construction material costs and the cost of labor. We recognize that major changes to these variables will have a significant impact on our analysis.

The discount rate is the other factor that poses a risk to our analysis and determining the present value of future costs for BART is beyond the project's scope. We can, however, show how a range of discount rates will affect the potential success of the project.

2.4. Secondary Data Collected

Estimating the project costs: We planned the renovation after choosing the staircases, which was accomplished using the data collected from the staircase maintenance inspection records provided by BART. We completed the project initiation, construction schedule, and cost documents using information collected from BART's forms, templates, and processes. We conducted cost estimation to help plan and budget, which is crucial for cost reduction.

In addition to the cost benefits on the maintenance side, there are additional benefits to implementing the stair tread upgrade that were not quantified in our project. The biggest benefit is the increase in passenger safety by having a new stair tread system that provides better grip, especially in wet conditions. An additional benefit is that there is a decreased risk of any of these staircases being out of compliance due to missing stair markings. Because of this, BART can decrease their liability to lawsuits from injuries related to the staircases. In addition to these, having an aluminum stair nosing installed will maintain its appearance until the end of the useful life. This contrasts with thermoplastic painted stairs, which can begin to chip away long before being out of compliance and due for replacement and may look less aesthetically pleasing to station users.

2.5. Simulation Process

Our simulation was made to take manual inputs for new construction material costs, annual labor rate increase, and discount rate (manual inputs for other material costs, labor hours, and year 0 labor rate are also possible but for the sake of this project are considered constant). The simulation outputs the net present value of the cost of replacement over 10 years, the net present value of the cost of doing nothing over 10 years, the total cost difference between the two scenarios over 10 years (a positive number indicates replacing the stair treads is less expensive), the percentage of savings over 10 years (over 30% is considered project success), the gap between the Net Present Value of Replacement and our 30% goal (gap analysis), and a graph showing how different discount rates affect the outcome of the project.

New Construction Material Costs	$	(87,895.47)
Annual Labor Rate Increase		4.120%
Discount Rate		0.00%
Net Present Value of Replacement	$	(235,078.77)
Net Present Value of "Doing Nothing"	$	(353,795.01)
Cost Savings over the 10 Years	$	118,716.24
Percentage Savings over the 10 Years		33.56%
Gap Analysis	$	12,577.74

Figure 13. Sample Simulation Inputs and Outputs

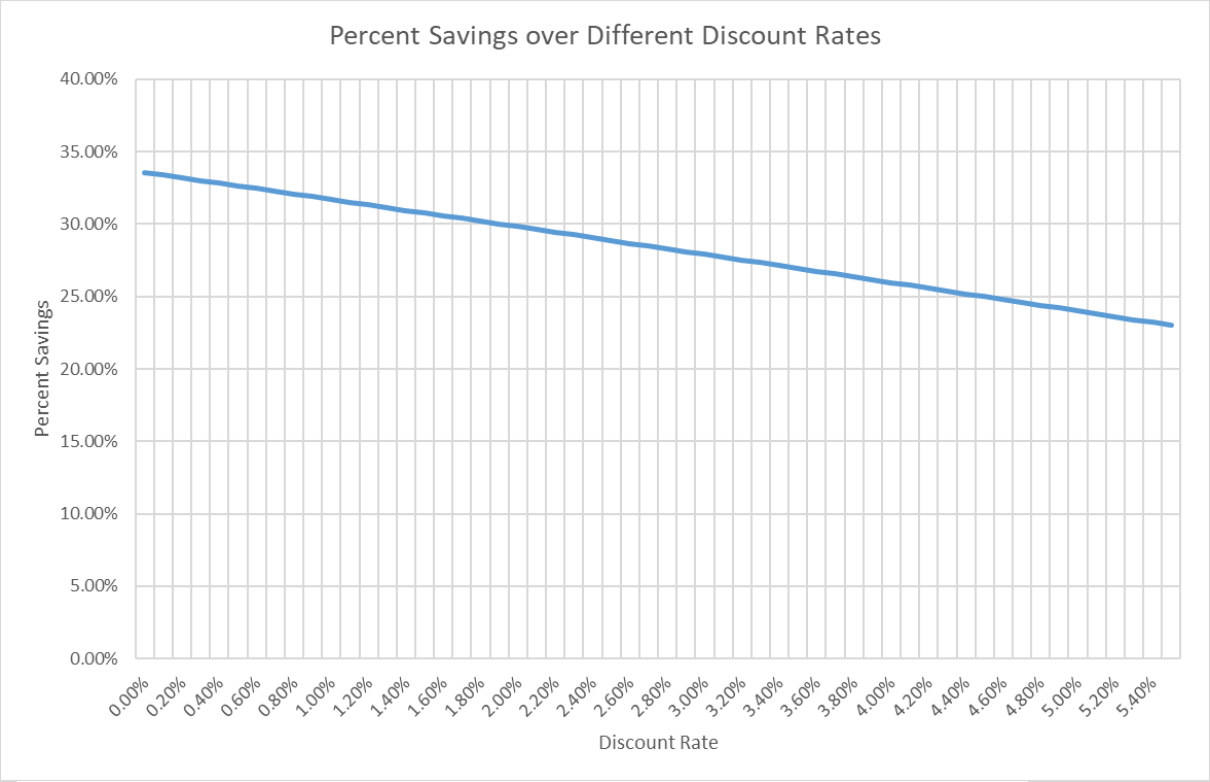

Figure 14. Graph from simulation showing percent savings over different discount rates

The simulation runs various calculations in the background and displays the information above quickly to give the user the most relevant information. See Appendix F for more information on the simulation.

3. Interpretation of Results

3.1. Results of the Simulation when exercised

The results of simulation show that the project can achieve the goal of saving 30% over 10 years if the discount rate of future costs is at or below 1.90%. The simulation also shows that as the discount rate increases past 1.90% the project will miss its goal by an increasing margin.

New Construction Material Costs	$	(87,895.47)
Annual Labor Rate Increase		4.120%
Discount Rate		1.90%
Net Present Value of Replacement	$	(223,872.12)
Net Present Value of "Doing Nothing"	$	(319,856.62)
Cost Savings over the 10 Years	$	95,984.49
Percentage Savings over the 10 Years		30.01%
Gap Analysis	$	27.51

Figure 15. Simulation Results with 1.90% discount rate

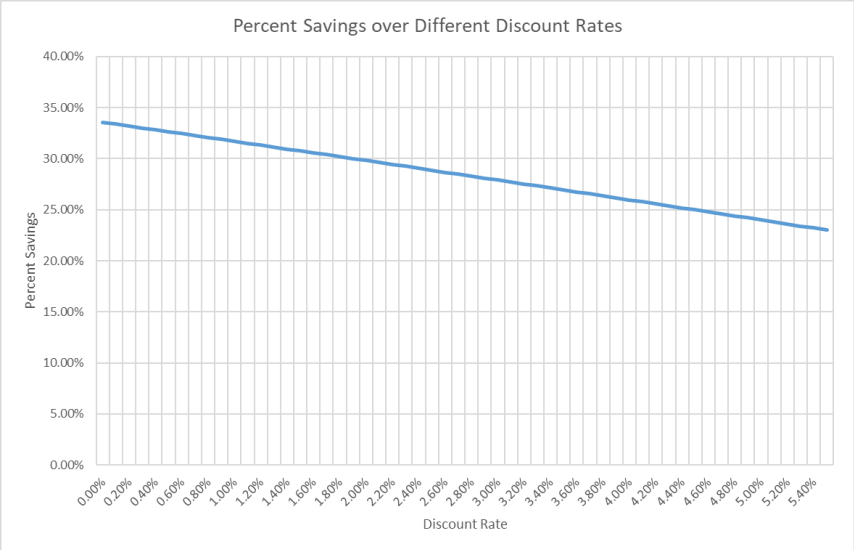

Figure 16. Simulation Results over increasing discount rates

We can also see how the various labor rate increases will affect the project's success. Figure 14 shows the results with a 4.12% labor cost increase over 10 years. But if we lower the rate to 3%, we see that we miss our 30% goal by about 2%.

New Construction Material Costs	$	(87,895.47)
Annual Labor Rate Increase		3.000%
Discount Rate		1.90%
Net Present Value of Replacement	$	(220,310.22)
Net Present Value of "Doing Nothing"	$	(305,747.12)
Cost Savings over the 10 Years	$	85,436.90
Percentage Savings over the 10 Years		27.94%
Gap Analysis	$	(6,287.24)

Figure 17. Simulation Results with 3% labor rate increase and 1.9% discount rate

We further exercise our simulation by seeing what discount rate would be needed to meet our goal with the new 3% labor rate.

New Construction Material Costs	$	(87,895.47)
Annual Labor Rate Increase		3.000%
Discount Rate		0.84%
Net Present Value of Replacement	$	(226,130.38)
Net Present Value of "Doing Nothing"	$	(323,045.27)
Cost Savings over the 10 Years	$	96,914.89
Percentage Savings over the 10 Years		30.00%
Gap Analysis	$	1.31

Figure 18. Simulation Results with 3% labor rate increase and 0.84% Discount Rate

The simulation shows that the discount rate would have to 0.84% or lower to achieve the project goal.

3.2. Mitigation Strategies Defined

Mitigation strategies for this project were aimed at reducing the overall costs of the maintenance burden of BART's staircases by installing aluminum nosing with non-slip, brightly colored, safety rubber inserts instead of non-slip, brightly colored, thermoplastic paint and included various aspects of planning, design, and ongoing maintenance. Here are some key mitigation strategies that were used:

Detailed Planning and Design: Our project used the assessment of the current condition of the staircase provided by BART to identify maintenance issues that necessitated the replacement of the existing paint with aluminum nosing and rubber inserts. The design detailed the specific type, dimensions, and installation methods for the aluminum nosing and safety rubber inserts to ensure long-term durability and safety.

Material Selection: Ensuring that the aluminum nosing and rubber inserts meet industry standards for durability, slip resistance, and safety. Choose materials that are UV-resistant to prevent fading and degradation from sunlight.

Installation Procedures: Hire experienced contractors with the appropriate expertise to ensure that the installation is carried out according to the design specifications to maximize longevity.

Regular Maintenance: Continue established routine inspection schedule to identify any signs of wear, damage, or slipping hazards and address any issues promptly to prevent further deterioration and maintain safety. Regularly clean the staircase and remove debris that could contribute to slip hazards. Use BART's rapid response protocol for addressing urgent

maintenance needs. Ensure that there is a dedicated budget for ongoing maintenance and replacement of the aluminum nosing and rubber inserts over the long term.

Documentation and Reporting: Use BART's record system to maintain detailed records of all maintenance activities, including inspections, repairs, and replacements. Provide reports to relevant authorities regarding the condition and safety of the staircases, as required.

Performance Monitoring: Use BART's customer feedback system for collecting data on accidents, wear and tear, and user feedback to continually assess the effectiveness of the mitigation strategy. Use the collected data to make any necessary adjustments to the maintenance strategy for continual process improvements.

Stakeholder Engagement: Keep the public and relevant stakeholders informed about the project's progress and ongoing maintenance efforts to build trust and transparency.

By implementing these mitigation strategies, the publicly funded construction project can effectively reduce the maintenance burden on the staircase of the public transit station and ensure the long-term safety and usability of the facility.

3.3 Synthesis of findings

The project aimed to address the root causes of maintenance costs and to provide a durable solution by using high-quality materials that meet industry standards and demonstrate a commitment to durability and safety. The UV-resistant materials will help maintain the aesthetic appeal of the staircase over time. Maintaining a proactive maintenance plan with routine inspections and cleaning protocols is a key mitigation strategy. It recognizes the importance of preventing issues before they become major maintenance burdens. Allocating sustainable funding for ongoing maintenance and replacement underscores a commitment to the project's

long-term viability. It mitigates the risk of neglecting maintenance due to budget constraints. Thorough record-keeping and reporting promote transparency and accountability by enabling stakeholders to track progress and understand the steps taken to maintain safety and functionality.

We feel that the strategies for this project are comprehensive and well-designed. They address various aspects, from planning and design to ongoing maintenance and stakeholder engagement. By implementing these strategies, the project aims to reduce the maintenance burden of the staircases while prioritizing safety and long-term sustainability. This approach minimizes the risks associated with neglect, improper installation, or insufficient funding, enhancing each individual transit station's staircases overall safety and long-term usability.

4. Conclusions and Recommendations

This project found a way to reduce costs and maintenance for stair treads in passenger stations. BART will replace the nose that covers staircase edges, creating a non-slip surface and markings for visually impaired riders to comply with laws. Once we finalized the selection of the staircases, we proceeded with planning the renovation project by replacing thermoplastic with aluminum alloy.

The project's goal is to replace specific staircases that are expected to reduce maintenance costs by 30% over a 10-year period after installation. To maximize operational cost savings and the effects of renovation, the team assessed the staircases based on BART's inspections, identified the risk, and conducted cost and schedule analysis. We are confident that this analysis proves that the team has delivered the project outcome to our sponsor's satisfaction.

Our recommendation is for BART to continue their operational maintenance requirements while waiting for funding to upgrade all staircases in each station. As with most maintenance actions, the priority should be on preventative maintenance, timely repairs, and proper documentation. BART's maintenance programs already do this, as these are not new requirements, but process improvement can only happen when the effects of a project are shown in the long-term through record keeping, lessons learned, and cost saving analysis. Through our cost analysis we believe that the long-term benefits of reducing the maintenance burden through upgrading the stair tread will be exponential as more stations are upgraded.

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National University

ENM 607 Capstone

Appendix A: Letter of Engagement

Prepared for: **San Francisco Bay Area Rapid Transit**

Prepared by: **Team 1**

Date: **10/12/2023**

Understandings:

1. Problem: (Define the market "pain" for which you will offer a "cure.")

The thermoplastic paint covering the nose of the stair treads in BART stations wears out too quickly for the current maintenance cycle because it is an expensive, time-consuming process to replace them.

2. Key question: (What is the one key dependent variable that will be the focus of this project?)

Will replacing the thermoplastic paint on the stairs with an aluminum nose covering reduce the operational cost of the stairs by 30% over 10 years?

3. Congruous logic: Identify the step-by-step (systems thinking) methodology you plan to use to arrive at the proposed "cure."

The main driver for operational cost is the degradation of the thermoplastic nose that covers the concrete tip of each stair. The independent variables are the number of passengers per year that use the stations, size of the staircases, labor costs, and material costs. These variables will be used as the criteria for which staircases are chosen to refurbish to maximize the benefit of the independent variables and reduce the maintenance costs after the installation.

After the staircases are chosen, we will plan the renovation of the staircases and analysis the costs. We will complete the project initiation and construction schedule documents using BART's forms templates and process. The last phase is to create a report and presentation on our findings and present them to the University faculty and sponsor at BART by October 31, 2023.

Activity	Name	Immediate Predecessors(s)	Optimistic (a)	Most Likely (m)	Pessimistic (b)	Activity Expected Completion Time (ECT)
A	Start Capstone A		0	0	0	0
B	finalize Letter of Engagement	A	20	22	27	22.5
C	Project Presentation	A	5	7	10	7.16666667
D	End of Capstone A	B,C	0	0	0	0
E	Start Capstone B	D	0	0	0	0
F	Evaluate the Starcases	E	7	10	14	10.1666667
G	Project Initiation Paperwork	F	10	15	17	14.5
H	Construction Schedule	F	10	16	20	15.6666667
I	End of Capstone B	H, G	0	0	0	0
J	Start Capstone C	I	0	0	0	0
K	Syntheses of findings	J	5	7	9	7
L	Final Report	K	14	16	24	17
M	Final Presentation	K	8	14	16	13.3333333
N	End Capstone C	L, M	0	0	0	0

Figure 1. Capstone Series Work Breakdown Structure with Completion Estimates

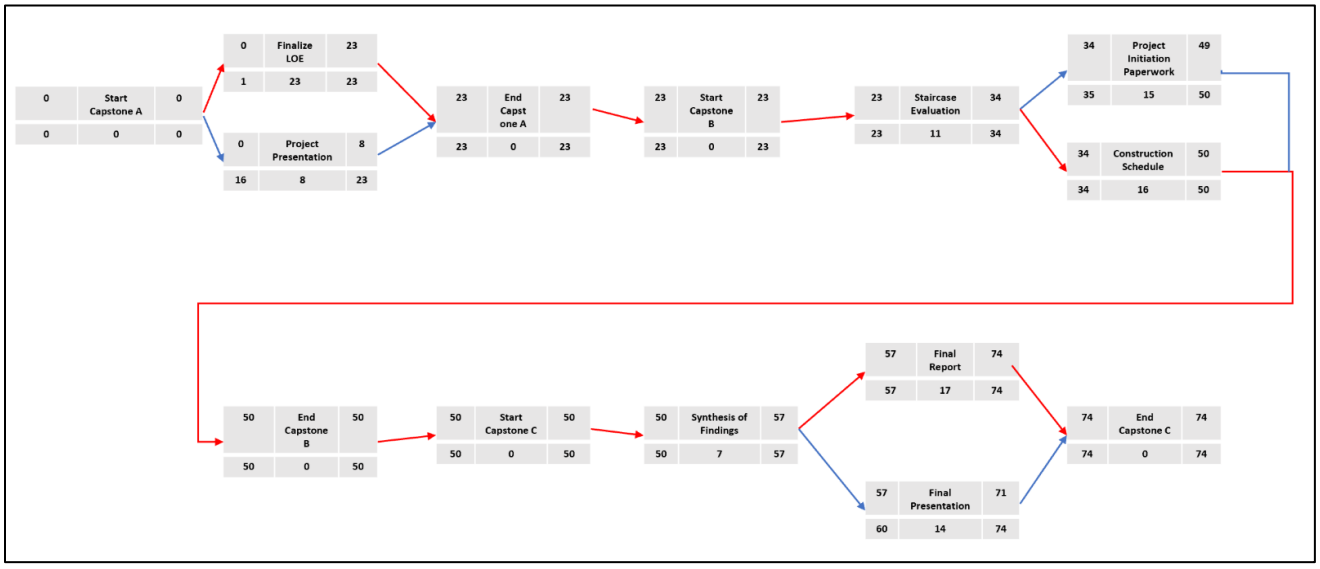


Figure 2. Capstone Series PERT Chart with Critical Path

From the PERT chart we have calculated a project completion percentage of 99% and are confident we can complete the project on time.

The team will utilize the phase-gate method to manage the project. The PERT chart indicates that most tasks are linear, and the team will mostly focus on one task at a time. We will use a systems approach at times in Capstones B and C, where more than one task can be completed simultaneously.

We have received the staircase evaluations and templates for most of the documents needed for the project already. If the sponsor does not provide the remaining BART documentation required, we will make our best effort to find open-source templates that are suitable substitutes.

Our team project SMART goal:

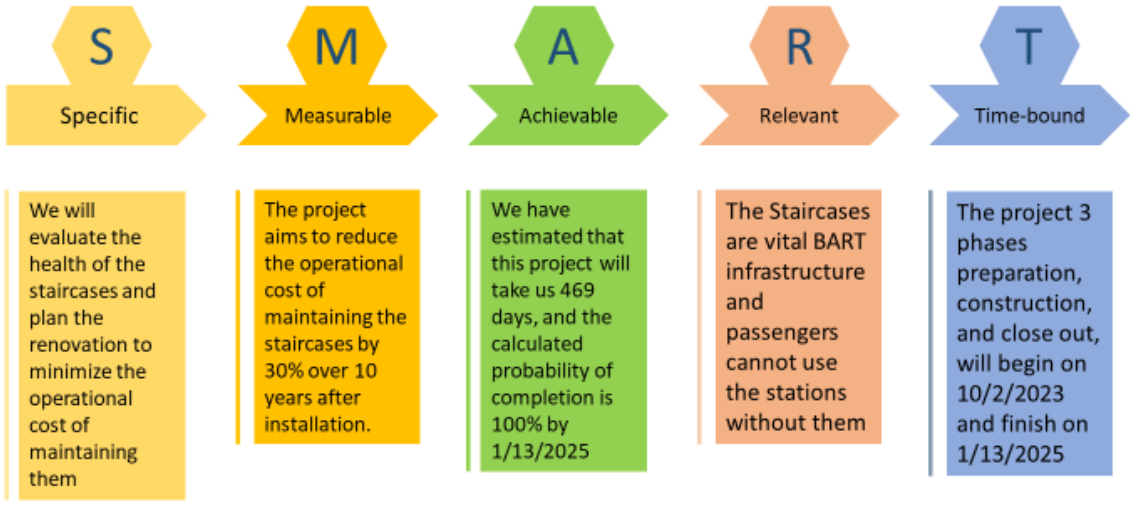


Figure 4. Project SMART goal

Ethical: We have examined the objectives of our project through the lens of ethical decision-making. We are confident that this project meets all ethical criteria and should be pursued. Our

criteria for choosing the staircases for renovation will emphasize safety (public benefit) and operational savings (stakeholders' benefit).

The central focus of this Capstone is to evaluate and identify four staircases for renovation. Evaluate some of the identified failure modes for root causes and ultimately propose actionable solutions for those risks that project managers can utilize to reduce or eliminate this failure.

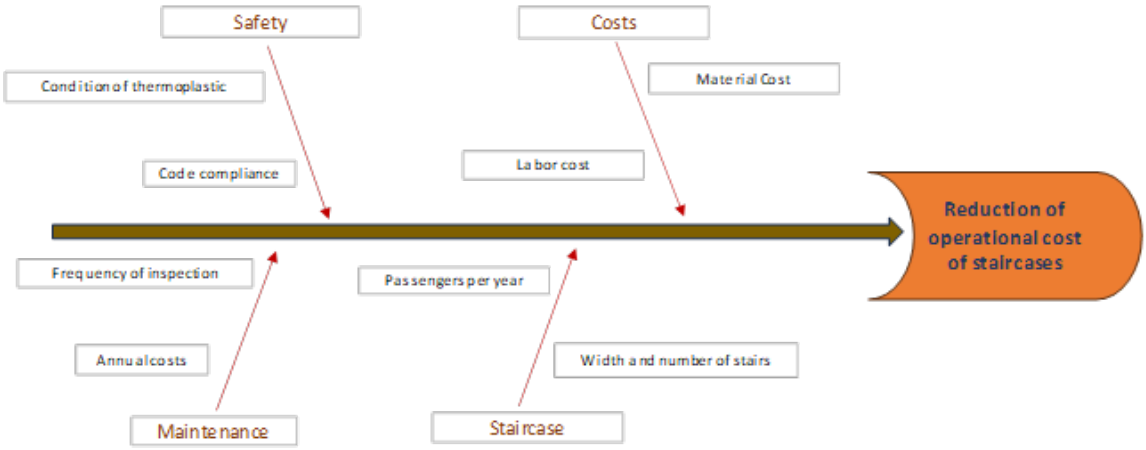


Figure 5. Project Cause and Effect Diagram

4. What content will be "in the scope" of this project?

The main scope of the project will be the evaluation of the various staircases by using documentation provided by BART and a scoring system devised by us to determine the condition of the staircase and plan the repair of 4 staircases to reduce the long-term maintenance costs. To tie in the various components of the project management principles that we have learned throughout our courses, we will use documentation provided by BART to include project initiation documentation, project execution plans, construction schedule (GANTT chart, WBS (Work Breakdown Schedule), etc.), budget analysis using data provided by BART. We will provide all documentation a BART Project Manager would provide for a project's inception.

5. What content will be “out-of-the-scope”? (This is to prevent the “scope creep.”)

Anything not listed as ‘in scope’ will be assumed to be ‘out of scope’ unless otherwise agreed upon. Everything in this project will use BART documentation to support the team’s conclusions. As such, the team will not be responsible for soliciting bids, contracts, or other requirements to start the project.

6. The agreed role of the client organization in support of this project:

BART will provide all documentation and all pertinent information related to the project. This will include inspection reports, pictures of the staircases, as-built drawings, previous maintenance, similar project documentation, etc., to help us complete the project.

7. The agree to the role of your instructor in support of the team’s effort:

The instructor will review and comment on the deliverable documents (Letter of Engagement, etc.). He will guide the project team through the process. The instructor and project team will communicate regularly. The team will be self-managed, and the instructor will only get involved if requested. Also, the instructor will arrange the time for your final presentation.

8. The expected team’s deliverables:

- Final written report
- PowerPoint presentation
- In-person presentation
- At the project's end, the final Written Report and PowerPoint presentation will be distributed to all stakeholders, along with electronic copies of both.

- The team will present in person (defend its work) to the client company, NU (National University) faculty, and invite guests at the scheduled time.
- The instructor will provide all templates and guidelines.

9. Project Milestones:

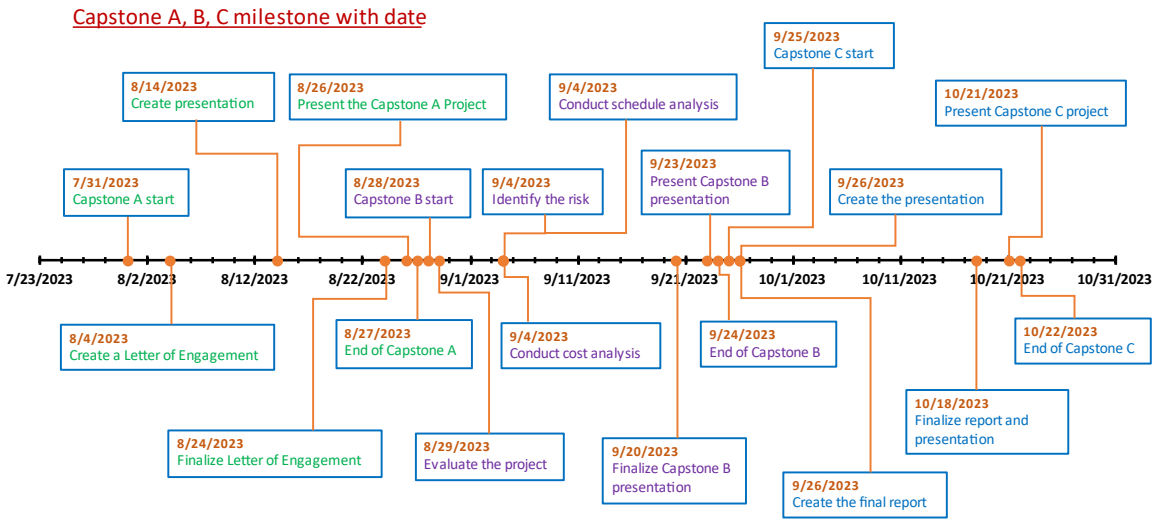


Figure 7. Capstone A, B, C milestone

Acceptance and Confidentiality:

The signatures below show that all parties have read and accepted this project proposal in its entirety.

It is understood that all client information shared with the team will remain confidential. If necessary, separate documents will govern the legal obligations of the stakeholders in this project.

Signatures:

Students:
Derry Moten

Dennis Miller

Dennis Miller

Gabriel Lind

Gabriel Lind

Chakrit Riddang

Chakrit Riddang

Instructor:
Derek Podobas

Derek Podobas 10/12/23

Client organization:
Linda Lee

Appendix B: Staircase Selection Matrix

Scores				
Criteria	**0**	**1**	**2**	**4**
Safety Risk to Passengers	None	Minimal	Elevated	Severe
Code Compliance	In Compliance	inimal Remediation Requir	derate Remediation Requi	OOC
Passengers Per Year	<600,000	600,001 - 1,500,000	1,500,001 - 3,000,000	>5,000,000
Number of Treads	5 or less	5 to 20	21 to 40	81+
Criteria	**Weights**			
Safety Risk to Passengers	0.45			
Code Compliance	0.32			
Passengers Per Year	0.16			
Number of Treads	0.07			
Total	**1.000**			

Location	Stair Designation	Safety risk to passengers	Code Compliance	Passengers per year	Treads	Weighted Score
A60 - Hayward	PL1	4	4	1	2	3.38
A10 - Lake Merritt	PL3	3	4	1	1	2.86
A10 - Lake Merritt	PL4	3	4	1	2	2.93
A60 - Hayward	C1	3	4	1	1	2.86
A10 - Lake Merritt	PL8	3	4	1	0	2.79
A10 - Lake Merritt	EE2	3	4	1	1	2.86
A10 - Lake Merritt	EE3	3	4	1	1	2.86
A50 - Bay Fair	EE1	3	4	1	1	2.86
A50 - Bay Fair	EE2	3	4	1	1	2.86
A50 - Bay Fair	EE3	3	4	1	1	2.86
A50 - Bay Fair	EE4	3	4	1	1	2.86
A60 - Hayward	EE1	3	4	1	1	2.86
A60 - Hayward	EE2	3	4	1	1	2.86
A60 - Hayward	EE3	3	4	1	1	2.86
A60 - Hayward	EE4	3	4	1	1	2.86
A80 - Union City	EE1	3	4	1	1	2.86
A80 - Union City	EE2	3	4	1	1	2.86
A80 - Union City	EE3	3	4	1	1	2.86
A80 - Union City	EE4	3	4	1	1	2.86
M80 - Balboa Park	W3	3	4	2	1	3.02
M90 - Daly City	PS7	3	4	2	1	3.02
M90 - Daly City	PS8	3	4	2	1	3.02
M90 - Daly City	PL2	3	4	2	1	3.02
K30 - MacArthur	EE1	3	4	2	1	3.02
K30 - MacArthur	EE2	3	4	2	1	3.02
K30 - MacArthur	EE3	3	4	2	1	3.02
K30 - MacArthur	EE4	3	4	2	1	3.02
A10 - Lake Merritt	W1	3	4	1	0	2.79
A50 - Bay Fair	E1B	3	4	1	1	2.86
A60 - Hayward	C3	3	4	1	2	2.93
M90 - Daly City	P3	4	2	2	1	2.83
M90 - Daly City	P4A	4	2	2	1	2.83
R30 - North Berkeley	W2	3	4	1	1	2.86
A10 - Lake Merritt	EE1	3	3	1	0	2.47
M10 - West Oakland	EE1	2	4	2	1	2.57
M10 - West Oakland	EE2	2	4	2	1	2.57
M10 - West Oakland	EE3	2	4	2	1	2.57
M10 - West Oakland	EE4	2	4	2	1	2.57
M20 - Montgomery	EE1	2	4	4	1	2.89
M20 - Montgomery	EE2	2	4	4	1	2.89
M20 - Montgomery	EE3	2	4	4	1	2.89
M20 - Montgomery	EE4	2	4	4	1	2.89
M30 - Powell	EE1	2	4	4	1	2.89
M30 - Powell	EE2	2	4	4	1	2.89
M30 - Powell	EE3	2	4	4	1	2.89
M30 - Powell	EE4	2	4	4	1	2.89
M40 - Civic Center	EE1	2	4	3	1	2.73
M40 - Civic Center	EE2	2	4	3	1	2.73

M40 - Civic Center	EE3	2	4	3	1	2.73
M40 - Civic Center	EE4	2	4	3	1	2.73
M50 - 16th St Mission	EE1	2	4	2	1	2.57
M50 - 16th St Mission	EE2	2	4	2	1	2.57
M50 - 16th St Mission	EE3	2	4	2	1	2.57
M50 - 16th St Mission	EE4	2	4	2	1	2.57
M50 - 16th St Mission	EE5	2	4	2	1	2.57
M50 - 16th St Mission	EE6	2	4	2	1	2.57
M60 - 24th St Mission	EE5	2	4	2	1	2.57
M60 - 24th St Mission	EE6	2	4	2	1	2.57
M70 - Glen Park	W1	2	4	1	0	2.34
M80 - Balboa Park	EE1	2	4	2	2	2.64
M90 - Daly City	PS1	2	4	2	3	2.71
M90 - Daly City	PS2	2	4	2	3	2.71
M90 - Daly City	PS3	2	4	2	3	2.71
M90 - Daly City	PS4	2	4	2	3	2.71
M90 - Daly City	PS5	2	4	2	3	2.71
M90 - Daly City	EE1	2	4	2	1	2.57
M90 - Daly City	EE2	2	4	2	2	2.64
M90 - Daly City	EE3	2	4	2	2	2.64
M90 - Daly City	EE4	2	4	2	1	2.57
R50 - El Cerrito Del Norte	EE1	2	4	2	1	2.57
R50 - El Cerrito Del Norte	EE2	2	4	2	1	2.57
R50 - El Cerrito Del Norte	EE3	2	4	2	1	2.57
R50 - El Cerrito Del Norte	EE4	2	4	2	1	2.57
A90 - Fremont	PL6	3	4	1	1	2.86
A90 - Fremont	PL8	3	4	1	1	2.86
L20 - West Dublin	PS1	3	3	0	3	2.52
L20 - West Dublin	PS3	3	3	0	3	2.52
A60 - Hayward	PS1	3	2	1	3	2.36
A90 - Fremont	PL7	3	1	1	1	1.9
A90 - Fremont	PL9	3	1	1	1	1.9
M10 - West Oakland	P3	3	1	2	3	2.2
M90 - Daly City	P4B	3	2	2	1	2.38
A10 - Lake Merritt	PL1	3	2	1	1	2.22
A10 - Lake Merritt	PL5	3	2	1	1	2.22
A40 - San leandro	P1	3	2	1	3	2.36
A40 - San leandro	P2	3	2	1	3	2.36
A50 - Bay Fair	PL1	3	2	1	1	2.22
A50 - Bay Fair	PL2	3	2	1	1	2.22
A50 - Bay Fair	E1A	3	2	1	1	2.22
A50 - Bay Fair	P1	3	2	1	2	2.29
A50 - Bay Fair	P2	3	2	1	2	2.29
A60 - Hayward	PS5	3	2	1	0	2.15
A60 - Hayward	PS6	3	2	1	0	2.15
A60 - Hayward	C2	3	2	1	1	2.22
A70 - South Hayward	C1	3	2	1	1	2.22
A70 - South Hayward	C2	3	2	1	1	2.22
A80 - Union City	C1	3	2	1	2	2.29
A80 - Union City	C2	3	2	1	2	2.29
A90 - Fremont	P1	3	2	1	2	2.29
M16 - Embarcadero	E1	3	1	4	2	2.45
M16 - Embarcadero	E2	3	1	4	2	2.45
M16 - Embarcadero	E5	3	1	4	2	2.45
M16 - Embarcadero	E6	3	1	4	2	2.45
M40 - Civic Center	E1	3	1	3	3	2.36
M40 - Civic Center	E2	3	1	3	3	2.36
M40 - Civic Center	E3	3	1	3	3	2.36
M40 - Civic Center	E5	3	1	3	3	2.36
M40 - Civic Center	E6	3	1	3	3	2.36
M40 - Civic Center	E7	3	1	3	3	2.36
M80 - Balboa Park	W1	3	1	2	1	2.06
M80 - Balboa Park	E3	3	1	2	1	2.06
M80 - Balboa Park	P2	3	1	2	1	2.06

M90 - Daly City	PL1	3	1	2	2	2.13
M90 - Daly City	P1	3	1	2	2	2.13
M90 - Daly City	P2	3	1	2	2	2.13
K10 - 12th St/City Center	P1	3	1	2	3	2.2
K10 - 12th St/City Center	P2	3	1	2	2	2.13
K10 - 12th St/City Center	P4	3	1	2	3	2.2
K10 - 12th St/City Center	P6	3	1	2	3	2.2
K20 - 19th St	P1	3	1	2	3	2.2
K20 - 19th St	P3	3	1	2	3	2.2
K20 - 19th St	P6	3	1	2	3	2.2
R60 - Richmond	PL1	3	1	1	1	1.9
R60 - Richmond	P1	3	1	1	3	2.04
L20 - West Dublin	E1	3	1	0	2	1.81
L20 - West Dublin	P2	3	1	0	2	1.81
L20 - West Dublin	P3	3	1	0	2	1.81
L20 - West Dublin	P4	3	1	0	2	1.81
L20 - West Dublin	E2	3	1	0	2	1.81
A60 - Hayward	PS2	2	2	1	3	1.91
M10 - West Oakland	P1	2	1	2	3	1.75
M10 - West Oakland	P2	2	1	2	3	1.75
M10 - West Oakland	P4	2	1	2	3	1.75
M16 - Embarcadero	E3	2	1	4	2	2
M16 - Embarcadero	P1	2	1	4	3	2.07
M16 - Embarcadero	P2	2	1	4	3	2.07
M20 - Montgomery	E1	2	1	4	1	1.93
M20 - Montgomery	E2	2	1	4	1	1.93
M20 - Montgomery	E3A	2	1	4	1	1.93
M20 - Montgomery	E3B	2	1	4	1	1.93
M20 - Montgomery	E4	2	1	4	1	1.93
M20 - Montgomery	E5	2	1	4	1	1.93
M20 - Montgomery	E6	2	1	4	1	1.93
M20 - Montgomery	E7	2	1	4	1	1.93
M20 - Montgomery	E8	2	1	4	1	1.93
M20 - Montgomery	P1	2	1	4	3	2.07
M20 - Montgomery	P2	2	1	4	3	2.07
M20 - Montgomery	P3	2	1	4	3	2.07
M30 - Powell	E1	2	1	4	3	2.07
M30 - Powell	E2	2	1	4	3	2.07
M30 - Powell	E3	2	1	4	3	2.07
M30 - Powell	E4	2	1	4	3	2.07
M30 - Powell	E5	2	1	4	3	2.07
M30 - Powell	E6	2	1	4	3	2.07
M30 - Powell	E7	2	1	4	3	2.07
M30 - Powell	E8	2	1	4	3	2.07
M30 - Powell	P1	2	1	4	3	2.07
M30 - Powell	P2	2	1	4	2	2
M30 - Powell	P3	2	1	4	3	2.07
M40 - Civic Center	E4	2	1	3	3	1.91
M40 - Civic Center	P1	2	1	3	3	1.91
M40 - Civic Center	P2	2	1	3	3	1.91
M50 - 16th St Mission	E1C	2	1	2	3	1.75
M50 - 16th St Mission	E1S	2	1	2	3	1.75
M50 - 16th St Mission	E2C	2	1	2	3	1.75
M50 - 16th St Mission	E2S	2	1	2	3	1.75
M50 - 16th St Mission	P2	2	1	2	2	1.68
M60 - 24th St Mission	E1C	2	1	2	3	1.75
M60 - 24th St Mission	E1S	2	1	2	3	1.75
M80 - Balboa Park	E1A	2	1	2	3	1.75
M80 - Balboa Park	E1B	2	1	2	3	1.75
M80 - Balboa Park	E2	2	1	2	3	1.75
M80 - Balboa Park	P1	2	1	2	3	1.75
K10 - 12th St/City Center	P3	2	1	2	2	1.68
K10 - 12th St/City Center	P5	2	1	2	2	1.68
K10 - 12th St/City Center	E1	2	1	2	2	1.68

K10 - 12th St/City Center	E2	2	1	2	2	1.68
K10 - 12th St/City Center	E3	2	1	2	2	1.68
K10 - 12th St/City Center	E4	2	1	2	2	1.68
K10 - 12th St/City Center	E5	2	1	2	2	1.68
K20 - 19th St	P2	2	1	2	2	1.68
K20 - 19th St	P4	2	1	2	2	1.68
K20 - 19th St	P5	2	1	2	2	1.68
K20 - 19th St	E1	2	1	2	2	1.68
K20 - 19th St	E2	2	1	2	2	1.68
K20 - 19th St	E3	2	1	2	2	1.68
K20 - 19th St	E4	2	1	2	2	1.68
K20 - 19th St	E5	2	1	2	2	1.68
R10 - Ashby	E1	2	1	1	2	1.52
R10 - Ashby	E2	2	1	1	2	1.52
R10 - Ashby	P1	2	1	1	1	1.45
R20 - Downtown Berkeley	E1	2	1	2	2	1.68
R20 - Downtown Berkeley	E2	2	1	2	2	1.68
R20 - Downtown Berkeley	E4	2	1	2	2	1.68
R20 - Downtown Berkeley	E5	2	1	2	2	1.68
R20 - Downtown Berkeley	E6	2	1	2	2	1.68
R30 - North Berkeley	W1	2	1	1	1	1.45
R30 - North Berkeley	P1	2	1	1	3	1.59
R30 - North Berkeley	P2	2	1	1	3	1.59
R40 - El Cerrito Plaza	PL1	2	1	1	1	1.45
R40 - El Cerrito Plaza	P1	2	1	1	3	1.59
R40 - El Cerrito Plaza	EE1	2	1	1	1	1.45
R40 - El Cerrito Plaza	EE3	2	1	1	1	1.45
R50 - El Cerrito Del Norte	PS1	2	1	2	3	1.75
R50 - El Cerrito Del Norte	PS3	2	1	2	3	1.75
R50 - El Cerrito Del Norte	PS4	2	1	2	3	1.75
R50 - El Cerrito Del Norte	PS5	2	1	2	1	1.61
R50 - El Cerrito Del Norte	PS6	2	1	2	2	1.68
R50 - El Cerrito Del Norte	P1	2	1	2	3	1.75
R50 - El Cerrito Del Norte	P2	2	1	2	3	1.75
R60 - Richmond	PL2	2	1	1	2	1.52
L10 - Castro Valley	EE1	2	3	0	1	1.93
L10 - Castro Valley	EE2	2	3	0	1	1.93
L30 - Dublin/Pleasanton	P1	2	3	1	2	2.16
L30 - Dublin/Pleasanton	P2	2	3	1	2	2.16
L30 - Dublin/Pleasanton	P3	2	3	1	2	2.16
L30 - Dublin/Pleasanton	EE1	2	3	1	1	2.09
L30 - Dublin/Pleasanton	EE2	2	3	1	1	2.09
A10 - Lake Merritt	PL2	1	3	1	0	1.57
A10 - Lake Merritt	E1A	1	3	1	2	1.71
A10 - Lake Merritt	E1B	1	3	1	2	1.71
A10 - Lake Merritt	E2	1	3	1	2	1.71
A10 - Lake Merritt	E3	1	3	1	2	1.71
A10 - Lake Merritt	E4	1	3	1	2	1.71
A10 - Lake Merritt	P1	1	3	1	2	1.71
A10 - Lake Merritt	P2	1	3	1	2	1.71
A20 - Fruitvale	PS1	1	3	2	4	2.01
A20 - Fruitvale	PS2	1	3	2	4	2.01
A20 - Fruitvale	P1	1	3	2	3	1.94
A30 - Coliseum	C1	3	1	1	2	1.97
A30 - Coliseum	E1	3	1	1	2	1.97
A30 - Coliseum	E2	3	1	1	1	1.9
A30 - Coliseum	E8	3	1	1	0	1.83
A30 - Coliseum	P1	3	1	1	3	2.04
A30 - Coliseum	P2	3	1	1	3	2.04
A40 - San leandro	EE1	3	1	1	1	1.9
A40 - San leandro	EE2	3	1	1	1	1.9
A40 - San leandro	EE3	3	1	1	1	1.9
A40 - San leandro	EE4	3	1	1	1	1.9
A70 - South Hayward	P1	3	1	1	2	1.97

A70 - South Hayward	P2	3	1	1	2	1.97
A70 - South Hayward	EE1	3	1	1	1	1.9
A70 - South Hayward	EE2	3	1	1	1	1.9
A70 - South Hayward	EE3	3	1	1	1	1.9
A70 - South Hayward	EE4	3	1	1	1	1.9
A80 - Union City	P1	3	1	1	2	1.97
A90 - Fremont	PL4	3	1	1	1	1.9
A90 - Fremont	PL5	3	1	1	1	1.9
M16 - Embarcadero	E4	3	1	4	2	2.45
M16 - Embarcadero	P3	3	1	4	3	2.52
M16 - Embarcadero	P4	3	1	4	3	2.52
M50 - 16th St Mission	P1	3	1	2	2	2.13
M60 - 24th St Mission	E2C	3	1	2	3	2.2
M60 - 24th St Mission	E2S	3	1	2	3	2.2
M60 - 24th St Mission	P1	3	1	2	2	2.13
M60 - 24th St Mission	P2	3	1	2	2	2.13
M70 - Glen Park	E1	3	1	1	1	1.9
M70 - Glen Park	E2	3	1	1	1	1.9
M70 - Glen Park	P1	3	1	1	3	2.04
M80 - Balboa Park	W2	3	1	2	1	2.06
M80 - Balboa Park	W4	3	1	2	2	2.13
M90 - Daly City	PS6	3	1	2	1	2.06
M90 - Daly City	PS9	3	1	2	0	1.99
K20 - 19th St	P7	3	1	2	2	2.13
K30 - MacArthur	P1	3	1	2	3	2.2
K30 - MacArthur	P2	3	1	2	3	2.2
K30 - MacArthur	P4	3	1	2	3	2.2
R60 - Richmond	EE1	3	1	1	1	1.9
R60 - Richmond	EE2	3	1	1	1	1.9
L10 - Castro Valley	P1	2	2	0	3	1.75
L20 - West Dublin	P1	3	1	0	2	1.81
L30 - Dublin/Pleasanton	PS1	3	1	1	4	2.11
L30 - Dublin/Pleasanton	PS2	3	1	1	4	2.11
L30 - Dublin/Pleasanton	PS3	3	1	1	4	2.11
A30 - Coliseum	E4	2	1	1	1	1.45
A60 - Hayward	PS3	0	0	1	3	0.37
A10 - Lake Merritt	PL6	0	0	1	0	0.16
A10 - Lake Merritt	PL7	0	0	1	0	0.16
A20 - Fruitvale	P2	0	0	2	3	0.53
A20 - Fruitvale	EE1	0	0	2	1	0.39
A20 - Fruitvale	EE2	0	0	2	1	0.39
A20 - Fruitvale	EE3	0	0	2	1	0.39
A20 - Fruitvale	EE4	0	0	2	1	0.39
A30 - Coliseum	E3	0	0	1	1	0.23
A30 - Coliseum	E5	0	0	1	1	0.23
A30 - Coliseum	E6	0	0	1	1	0.23
A30 - Coliseum	E7	0	0	1	1	0.23
A30 - Coliseum	EE1	0	0	1	1	0.23
A30 - Coliseum	EE2	0	0	1	1	0.23
A60 - Hayward	PS4	0	0	1	3	0.37
A60 - Hayward	P1	0	0	1	3	0.37
A60 - Hayward	P2	0	0	1	3	0.37
A80 - Union City	EE5	0	0	1	2	0.3
A80 - Union City	EE6	0	0	1	2	0.3
A90 - Fremont	PL1	0	0	1	1	0.23
A90 - Fremont	PL2	0	0	1	1	0.23
A90 - Fremont	PL3	0	0	1	1	0.23
K30 - MacArthur	P3	0	0	2	2	0.46
R40 - El Cerrito Plaza	EE2	0	0	1	2	0.3
A30 - Coliseum	EE4	0	0	1	2	0.3
R20 - Downtown Berkeley	P1	0	0	2	1	0.39
R20 - Downtown Berkeley	P2	0	0	2	1	0.39
R20 - Downtown Berkeley	P3	0	0	2	1	0.39
R20 - Downtown Berkeley	P4	0	0	2	1	0.39

R40 - El Cerrito Plaza	P2	0	0	1	3	0.37
R40 - El Cerrito Plaza	EE4	0	0	1	1	0.23
R50 - El Cerrito Del Norte	PS2	0	0	2	3	0.53
R60 - Richmond	C1	0	0	1	2	0.3
R60 - Richmond	E1	0	0	1	2	0.3
L10 - Castro Valley	P2	0	0	0	3	0.21
L10 - Castro Valley	Plaza	0	0	0	1	0.07
L20 - West Dublin	PS2	0	0	0	3	0.21
L20 - West Dublin	EE1	0	0	0	1	0.07
L20 - West Dublin	EE2	0	0	0	1	0.07
A20	PM	1	2	2	2	1.55

Appendix C: Rockridge Invoice

nystrom

INVOICE

Phone: 8005472635
Fax: 8003178770

Invoice #	Invoice Date	Customer #	Page #
			1

Remit To : Lockbox 446038
P.O. Box 64048
St. Paul, MN 55164-0017

Purchase Order	Sales Order #

Bill To

Ship To

Attn:

E-Invoice Program	E-Invoice Email
Yes	

Account Manager	Collect/Prepaid	Location	Carrier
	LINE ITEM	EBP	King

Item # / Description	Qty Ordered	Qty Shipped	Item Price	UOM	Extended Price
RRS E1 MID LANDING-W95.0XL53.0 Stair Tread, Two PartRecycled Rubber- EcoTread, Long Nose Angled, Drilled For Bolt In, Renovation, 1st 3 Ribs Safety Yellow, Black Ribs, 11" Wide	1.00	1.00	4,649.80	FT	4,649.80
RRS E1 TOP LANDING-W95.0XL95.0 Stair Tread, Two PartRecycled Rubber- EcoTread, Long Nose Angled, Drilled For Bolt In, Renovation, 1st 3 Ribs Safety Yellow, Black Ribs, 11" Wide	1.00	1.00	7,838.35	FT	7,838.35
RRS E1 BOT LANDING-W95.0XL95.0 Stair Tread, Two PartRecycled Rubber- EcoTread, Long Nose Angled, Drilled For Bolt In, Renovation, All Black Ribs, 11" Wide	1.00	1.00	7,819.93	FT	7,819.93
FREIGHT Delivery Charge	1.00	1.00	387.00	EA	387.00
STMB-A11D-ECO-V3C5-BART-45.0 Two Stage Rib, Stair Tread,Bar Ribbed Eco Tread, Long Nose Angled, Drilled For Bolt In, First 3 Ribs Safety Yellow, Renovation, Black Recycled Rubber Ribs 11" Wide 44 pcs @ 45"	165.00	165.00	69.78	FT	11,513.70

nystrom

E INVOICE

Phone: 8005472635
Fax: 8003178770
Remit To : Lockbox 446038
P.O. Box 64048
St. Paul, MN 55164-0017

Invoice #	Invoice Date	Customer #	Page #
			2

Purchase Order	Sales Order #

Bill To

Ship To

Attn:

E-Invoice Program	E-Invoice Email
Yes	

Account Manager	Collect/Prepaid	Location	Carrier
	LINE ITEM	EBP	King

Item # / Description	Qty Ordered	Qty Shipped	Item Price	UOM	Extended Price

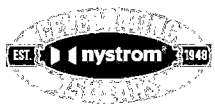
Comments:

Sales Amount:	32,208.78
Misc. Amount:	0.00
Freight:	0.00
Sales Tax:	3,261.73
Subtotal:	35,470.51
Amount Received:	0.00
Total Due USD:	**$35,470.51**

Terms Net 30

A 3% surcharge will be added to invoices that are paid by credit card.

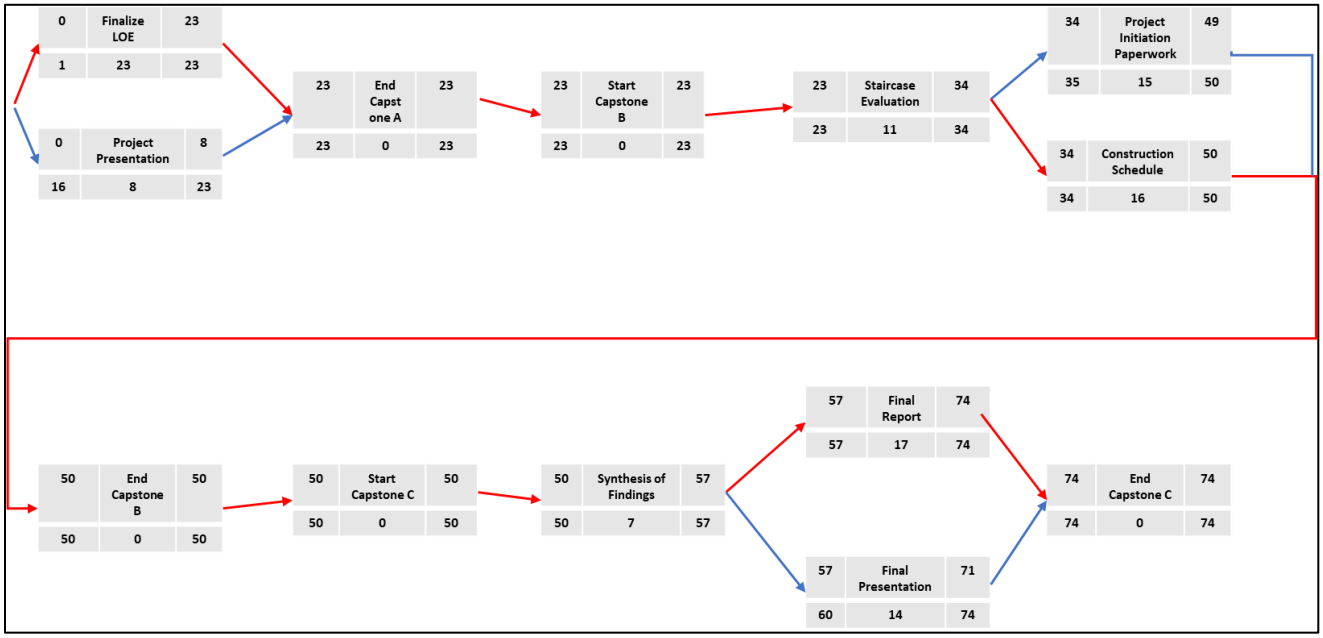
Payroll Specialist/Accounting Assistant



9300 73rd Avenue North
Minneapolis, MN 55428

Appendix D: PERT Chart and Completion Probability Calculations

Activity	Name	Immediate Predecessors(s)	Optimistic (a)	Most Likely (m)	Pessimistic (b)	Activity Expected Completion Time (ECT)
A	Start Capstone A		0	0	0	0
B	finalize Letter of Engagement	A	20	22	27	22.5
C	Project Presentation	A	5	7	10	7.16666667
D	End of Capstone A	B,C	0	0	0	0
E	Start Capstone B	D	0	0	0	0
F	Evaluate the Starcases	E	7	10	14	10.1666667
G	Project Initiation Paperwork	F	10	15	17	14.5
H	Construction Schedule	F	10	16	20	15.6666667
I	End of Capstone B	H, G	0	0	0	0
J	Start Capstone C	I	0	0	0	0
K	Syntheses of findings	J	5	7	9	7
L	Final Report	K	14	16	24	17
M	Final Presentation	K	8	14	16	13.3333333
N	End Capstone C	L, M	0	0	0	0



Activity	Name	ES	LS	EF	LF	Slack	Step on the Critical Path? Y/N	Project Variance
A	Start Capstone A	0	0	0	0	0	Y	0
B	finalize Letter of Engagement	0	0	23	23	0	Y	1.361111111
C	Project Presentation	0	16	8	23	16	N	0
D	End of Capstone A	**23**	**23**	**23**	**23**	0	Y	0
E	Start Capstone B	**23**	**23**	**23**	**23**	0	Y	0
F	Evaluate the Starcases	23	23	34	34	0	Y	1.361111111
G	Project Initiation Paperwork	34	35	49	50	1	N	0
H	Construction Schedule	34	34	50	50	0	y	2.777777778
I	End of Capstone B	**50**	**50**	**50**	**50**	0	Y	0
J	Start Capstone C	**50**	**50**	**50**	**50**	0	Y	0
K	Syntheses of findings	50	50	57	57	0	Y	0.444444444
L	Final Report	57	57	74	74	0	y	2.777777778
M	Final Presentation	57	60	71	74	3	N	0
N	End Capstone C	**74**	**74**	**74**	**74**	0	Y	0

The Variance of each step is: ((b-a)/6)^2

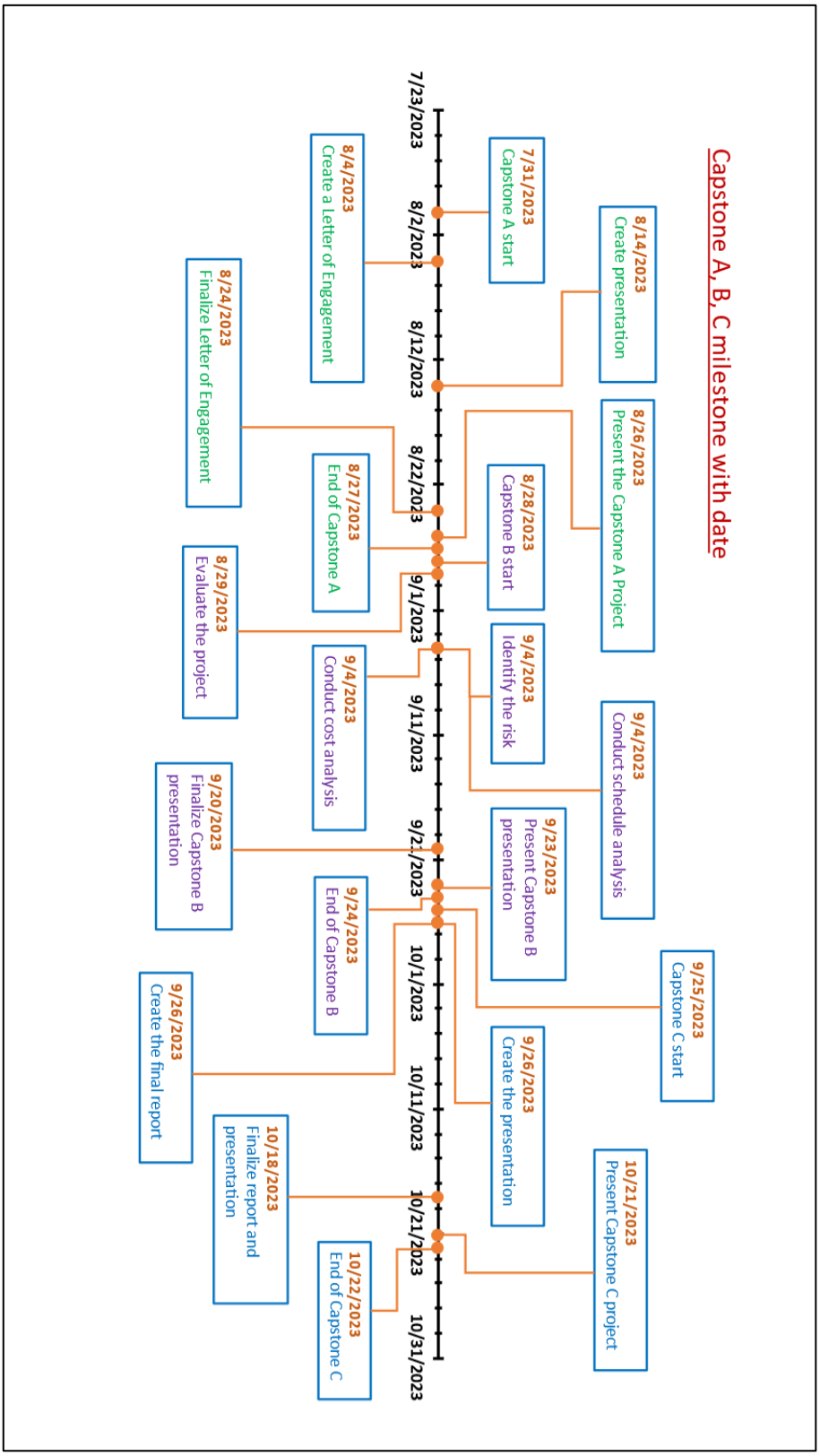
Project Standard Deviation	2.95
Required Completion Time (in Days) = x	96
Expected Completion Time (in Days) = x(bar)	74
z score	7.4576
Probability of Completion = P	1

The project standard deviation is the square root of the sum of variance of each step.

$$Z = \frac{(x - \overline{x})}{\sigma}$$

The probability of completing our project on time is 100%

Appendix E: Project Milestones



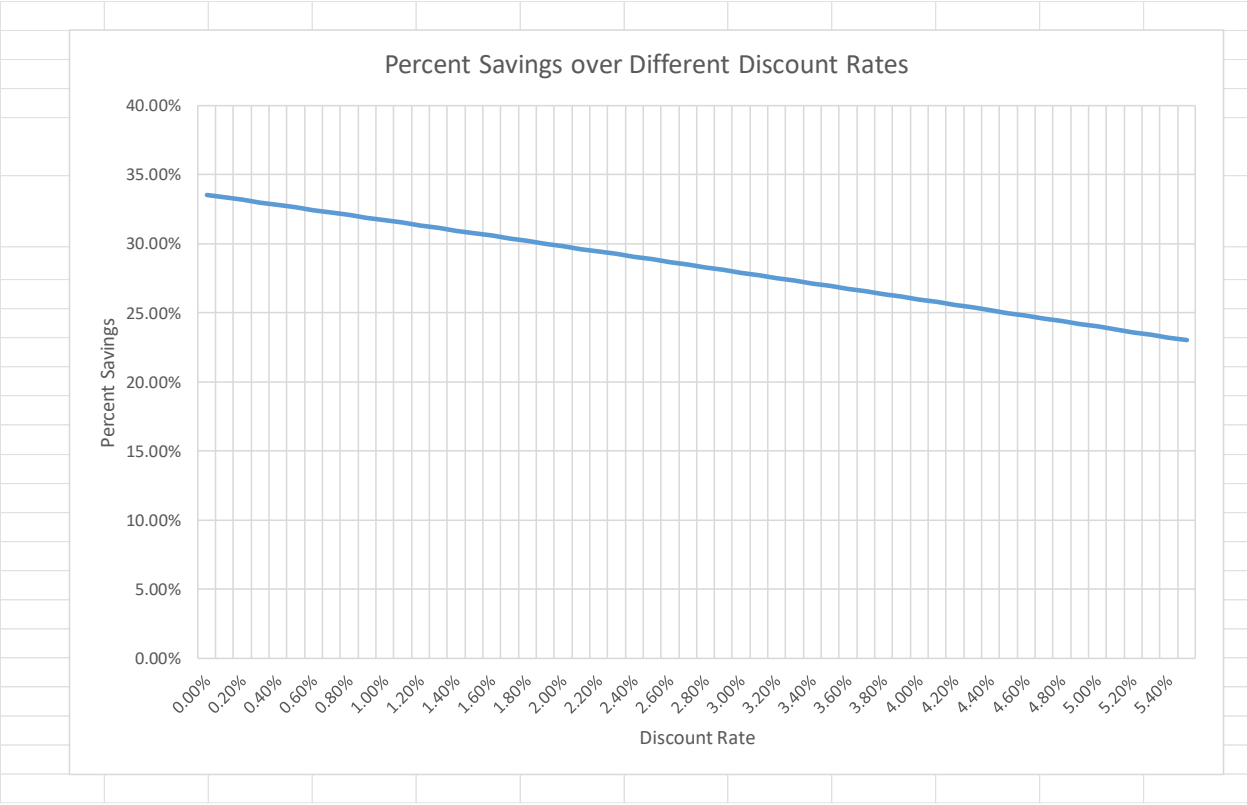
Appendix F: Simulation Model (Screenshots)

Main Page:

User interface showing inputs in light blue and outputs in white & green (or red if below 30%)

New Construction Material Costs	$	(87,895.47)
Annual Labor Rate Increase		4.120%
Discount Rate		1.90%
Net Present Value of Replacement	$	(223,872.12)
Net Present Value of "Doing Nothing"	$	(319,856.62)
Cost Savings over the 10 Years	$	95,984.49
Percentage Savings over the 10 Years		30.01%
Gap Analysis	$	27.51

Output graph on the main page showing percentage savings over a range of discount rates



Background Data Page:

This is the main working data chart that calculates the expenses of each scenario based on material costs, labor hours, labor costs, and annual labor rate increases. In here the light grey boxes are able to take user inputs but they are left off of the user interface because we have calculated those over the course of the project.

	Stair Tread Replacement								
Year	Materials	Labor Hours (const)	Labor Hours (PM)	Labor Hours (finance)	Labor Rate (Const)	Labor Rate (PM)	Labor Rate (finance)	Overhead	Labor + Overhead Cost
0	$ (87,895.47)	320	92	40	$ (121.87)	$ (194.86)	$ (157.12)	$ (9,481.55)	$ (72,691.87)
1	$ -	48			$ (126.89)	$ (202.89)	$ (163.59)	$ (913.62)	$ (7,004.39)
2	$ -	48			$ (132.12)	$ (211.25)	$ (170.33)	$ (951.26)	$ (7,292.97)
3	$ -	48			$ (137.56)	$ (219.95)	$ (177.35)	$ (990.45)	$ (7,593.44)
4	$ -	48			$ (143.23)	$ (229.01)	$ (184.66)	$ (1,031.25)	$ (7,906.29)
5	$ -	48			$ (149.13)	$ (238.45)	$ (192.27)	$ (1,073.74)	$ (8,232.03)
6	$ -	48			$ (155.28)	$ (248.27)	$ (200.19)	$ (1,117.98)	$ (8,571.18)
7	$ -	48			$ (161.67)	$ (258.50)	$ (208.43)	$ (1,164.04)	$ (8,924.32)
8	$ -	48			$ (168.33)	$ (269.15)	$ (217.02)	$ (1,212.00)	$ (9,292.00)
9	$ -	48			$ (175.27)	$ (280.24)	$ (225.96)	$ (1,261.93)	$ (9,674.83)
	Total								$ (235,078.77)

"Do Nothing" (Each Staircase)								
Materials	Labor Hours (const)	Labor Hours (PM)	Labor Hours (finance)	Labor Rate (Const)	Labor Rate (PM)	Labor Rate (finance)	Overhead	Labor + Overhead
$ (300.00)	86	4		$ (121.87)	$ (194.86)	$ (157.12)	$ (1,689.04)	$ (12,949.30)
	12			$ (126.89)	$ (202.89)	$ (163.59)	$ (228.40)	$ (1,751.10)
$ (300.00)	86	4		$ (132.12)	$ (211.25)	$ (170.33)	$ (1,831.08)	$ (14,038.30)
	12			$ (137.56)	$ (219.95)	$ (177.35)	$ (247.61)	$ (1,898.36)
$ (300.00)	86	4		$ (143.23)	$ (229.01)	$ (184.66)	$ (1,985.07)	$ (15,218.89)
	12			$ (149.13)	$ (238.45)	$ (192.27)	$ (268.44)	$ (2,058.01)
$ (300.00)	86	4		$ (155.28)	$ (248.27)	$ (200.19)	$ (2,152.01)	$ (16,498.76)
	12			$ (161.67)	$ (258.50)	$ (208.43)	$ (291.01)	$ (2,231.08)
$ (300.00)	86	4		$ (168.33)	$ (269.15)	$ (217.02)	$ (2,332.99)	$ (17,886.26)
	12			$ (175.27)	$ (280.24)	$ (225.96)	$ (315.48)	$ (2,418.71)
								$ (88,448.75)
Total For All 4 Staircases								$ (353,795.01)

This simulation automatically updates the yearly costs and cumulative costs for each scenario.

	Cumulative Costs	
Year	Replacement	No Replacement
0	$ (160,587.34)	$ (52,997.20)
1	$ (167,591.72)	$ (60,001.58)
2	$ (174,884.69)	$ (117,354.79)
3	$ (182,478.13)	$ (124,948.23)
4	$ (190,384.41)	$ (187,023.77)
5	$ (198,616.44)	$ (195,255.80)
6	$ (207,187.62)	$ (262,450.83)
7	$ (216,111.94)	$ (271,375.14)
8	$ (225,403.94)	$ (344,120.18)
9	$ (235,078.77)	$ (353,795.01)

	Costs each year	
Year	Replacement	Do Nothing
0	$ (160,587.34)	$ (52,997.20)
1	$ (7,004.39)	$ (7,004.39)
2	$ (7,292.97)	$ (57,353.21)
3	$ (7,593.44)	$ (7,593.44)
4	$ (7,906.29)	$ (62,075.55)
5	$ (8,232.03)	$ (8,232.03)
6	$ (8,571.18)	$ (67,195.03)
7	$ (8,924.32)	$ (8,924.32)
8	$ (9,292.00)	$ (72,745.04)
9	$ (9,674.83)	$ (9,674.83)

The simulation automatically does the NPV calculations that are shown on the User Interface page.

Net Present Value		Replacement	No Replacement
Discount Rate	1.90%	($223,872.12)	($319,856.62)
Cost Benefit Over 10 Years	($95,984.49)		
ngs over 10 Years	30.0%		

Lastly the simulation calculates the information for the graph shown on the user interface page.

	NPV over a range of inflation rates and constant labor rate				4.12%
Discount	Replacement	No Replacement	Savings	% savings	
0.00%	($235,078.77)	($353,795.01)	($118,716.24)	33.56%	
0.10%	($234,453.32)	($351,880.17)	($117,426.85)	33.37%	
0.20%	($233,832.05)	($349,980.40)	($116,148.35)	33.19%	
0.30%	($233,214.91)	($348,095.55)	($114,880.65)	33.00%	
0.40%	($232,601.85)	($346,225.49)	($113,623.63)	32.82%	
0.50%	($231,992.85)	($344,370.07)	($112,377.21)	32.63%	
0.60%	($231,387.87)	($342,529.15)	($111,141.28)	32.45%	
0.70%	($230,786.87)	($340,702.60)	($109,915.73)	32.26%	
0.80%	($230,189.80)	($338,890.28)	($108,700.47)	32.08%	
0.90%	($229,596.65)	($337,092.05)	($107,495.41)	31.89%	
1.00%	($229,007.36)	($335,307.79)	($106,300.44)	31.70%	
1.10%	($228,421.90)	($333,537.37)	($105,115.46)	31.52%	
1.20%	($227,840.25)	($331,780.64)	($103,940.40)	31.33%	
1.30%	($227,262.35)	($330,037.49)	($102,775.14)	31.14%	
1.40%	($226,688.19)	($328,307.79)	($101,619.60)	30.95%	
1.50%	($226,117.72)	($326,591.41)	($100,473.69)	30.76%	
1.60%	($225,550.91)	($324,888.22)	($99,337.31)	30.58%	
1.70%	($224,987.73)	($323,198.11)	($98,210.38)	30.39%	
1.80%	($224,428.15)	($321,520.95)	($97,092.80)	30.20%	
1.90%	($223,872.12)	($319,856.62)	($95,984.49)	30.01%	
2.00%	($223,319.63)	($318,205.00)	($94,885.37)	29.82%	
2.10%	($222,770.63)	($316,565.97)	($93,795.34)	29.63%	
2.20%	($222,225.10)	($314,939.43)	($92,714.32)	29.44%	
2.30%	($221,683.01)	($313,325.24)	($91,642.23)	29.25%	
2.40%	($221,144.32)	($311,723.30)	($90,578.99)	29.06%	
2.50%	($220,609.00)	($310,133.50)	($89,524.50)	28.87%	
2.60%	($220,077.02)	($308,555.72)	($88,478.70)	28.68%	
2.70%	($219,548.36)	($306,989.85)	($87,441.49)	28.48%	
2.80%	($219,022.98)	($305,435.78)	($86,412.80)	28.29%	
2.90%	($218,500.85)	($303,893.41)	($85,392.55)	28.10%	
3.00%	($217,981.95)	($302,362.62)	($84,380.67)	27.91%	
3.10%	($217,466.25)	($300,843.31)	($83,377.06)	27.71%	
3.20%	($216,953.71)	($299,335.38)	($82,381.67)	27.52%	
3.30%	($216,444.32)	($297,838.72)	($81,394.41)	27.33%	
3.40%	($215,938.03)	($296,353.23)	($80,415.20)	27.13%	
3.50%	($215,434.83)	($294,878.81)	($79,443.98)	26.94%	
3.60%	($214,934.69)	($293,415.36)	($78,480.66)	26.75%	
3.70%	($214,437.58)	($291,962.77)	($77,525.19)	26.55%	
3.80%	($213,943.47)	($290,520.95)	($76,577.48)	26.36%	
3.90%	($213,452.34)	($289,089.80)	($75,637.46)	26.16%	
4.00%	($212,964.16)	($287,669.23)	($74,705.06)	25.97%	
4.10%	($212,478.91)	($286,259.13)	($73,780.22)	25.77%	
4.20%	($211,996.56)	($284,859.42)	($72,862.87)	25.58%	
4.30%	($211,517.08)	($283,470.00)	($71,952.93)	25.38%	
4.40%	($211,040.45)	($282,090.78)	($71,050.34)	25.19%	
4.50%	($210,566.64)	($280,721.67)	($70,155.03)	24.99%	
4.60%	($210,095.64)	($279,362.57)	($69,266.93)	24.79%	
4.70%	($209,627.41)	($278,013.40)	($68,385.99)	24.60%	
4.80%	($209,161.94)	($276,674.07)	($67,512.13)	24.40%	
4.90%	($208,699.19)	($275,344.49)	($66,645.30)	24.20%	
5.00%	($208,239.15)	($274,024.57)	($65,785.42)	24.01%	
5.10%	($207,781.79)	($272,714.23)	($64,932.43)	23.81%	
5.20%	($207,327.09)	($271,413.37)	($64,086.28)	23.61%	
5.30%	($206,875.03)	($270,121.93)	($63,246.90)	23.41%	
5.40%	($206,425.58)	($268,839.81)	($62,414.23)	23.22%	
5.50%	($205,978.72)	($267,566.93)	($61,588.21)	23.02%	
5.60%	($205,534.43)	($266,303.21)	($60,768.78)	22.82%	
5.70%	($205,092.69)	($265,048.57)	($59,955.88)	22.62%	
5.80%	($204,653.47)	($263,802.93)	($59,149.46)	22.42%	
5.90%	($204,216.76)	($262,566.21)	($58,349.45)	22.22%	
6.00%	($203,782.53)	($261,338.33)	($57,555.79)	22.02%	
6.10%	($203,350.77)	($260,119.21)	($56,768.44)	21.82%	
6.20%	($202,921.44)	($258,908.78)	($55,987.33)	21.62%	
6.30%	($202,494.54)	($257,706.95)	($55,212.41)	21.42%	
6.40%	($202,070.04)	($256,513.66)	($54,443.63)	21.22%	
6.50%	($201,647.92)	($255,328.84)	($53,680.92)	21.02%	
6.60%	($201,228.16)	($254,152.39)	($52,924.24)	20.82%	
6.70%	($200,810.74)	($252,984.27)	($52,173.53)	20.62%	
6.80%	($200,395.64)	($251,824.38)	($51,428.74)	20.42%	
6.90%	($199,982.85)	($250,672.66)	($50,689.81)	20.22%	
7.00%	($199,572.34)	($249,529.04)	($49,956.70)	20.02%	
7.10%	($199,164.09)	($248,393.44)	($49,229.36)	19.82%	
7.20%	($198,758.09)	($247,265.81)	($48,507.72)	19.62%	
7.30%	($198,354.31)	($246,146.06)	($47,791.75)	19.42%	
7.40%	($197,952.75)	($245,034.14)	($47,081.39)	19.21%	
7.50%	($197,553.37)	($243,929.97)	($46,376.60)	19.01%	
7.60%	($197,156.17)	($242,833.49)	($45,677.32)	18.81%	
7.70%	($196,761.12)	($241,744.63)	($44,983.51)	18.61%	
7.80%	($196,368.21)	($240,663.32)	($44,295.11)	18.41%	
7.90%	($195,977.42)	($239,589.51)	($43,612.09)	18.20%	
8.00%	($195,588.73)	($238,523.12)	($42,934.39)	18.00%	
8.10%	($195,202.13)	($237,464.09)	($42,261.97)	17.80%	
8.20%	($194,817.59)	($236,412.37)	($41,594.78)	17.59%	
8.30%	($194,435.11)	($235,367.88)	($40,932.77)	17.39%	
8.40%	($194,054.66)	($234,330.57)	($40,275.91)	17.19%	
8.50%	($193,676.23)	($233,300.37)	($39,624.14)	16.98%	
8.60%	($193,299.80)	($232,277.23)	($38,977.43)	16.78%	
8.70%	($192,925.36)	($231,261.09)	($38,335.73)	16.58%	
8.80%	($192,552.89)	($230,251.88)	($37,698.99)	16.37%	
8.90%	($192,182.38)	($229,249.55)	($37,067.17)	16.17%	
9.00%	($191,813.80)	($228,254.03)	($36,440.23)	15.96%	
9.10%	($191,447.14)	($227,265.28)	($35,818.14)	15.76%	
9.20%	($191,082.40)	($226,283.23)	($35,200.83)	15.56%	
9.30%	($190,719.54)	($225,307.83)	($34,588.29)	15.35%	
9.40%	($190,358.57)	($224,339.02)	($33,980.45)	15.15%	
9.50%	($189,999.46)	($223,376.75)	($33,377.29)	14.94%	
9.60%	($189,642.19)	($222,420.96)	($32,778.77)	14.74%	
9.70%	($189,286.76)	($221,471.60)	($32,184.84)	14.53%	
9.80%	($188,933.15)	($220,528.61)	($31,595.46)	14.33%	
9.90%	($188,581.34)	($219,591.94)	($31,010.60)	14.12%	
10.00%	($188,231.33)	($218,661.54)	($30,430.21)	13.92%	

Appendix G: Project Decomposition & Cause and Effect Diagram