195B Senior Project:

Spartan Superway

Project Cost Estimation, Scheduling and Risk Analysis

Charles W. Davidson College of Engineering
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4. Executive Summary

The case study into two comparable projects showed higher chances of unforeseen events happening even though planning is done beforehand. The risks identified in this paper can be used to better plan the project. The team has identified that it will take approximately 498 days to finish the construction and testing of the track. The cost of the test track is estimated to be between $840, 000 to $1.5 Million.

5. Introduction

Being the powerhouse of the Silicon Valley, San Jose is constantly developing and seeking innovative ideas to shape the city. Today, public transportation plays a critical role in our day to day lives, especially in a fast paced city such as San Jose. In an effort to construct a faster, automated method of public transportation, a team of engineers have been actively working on the Spartan Superway project. This method of transportation is sought out to be fully autonomous and solar powered, making it eco-friendly with virtually zero carbon emissions. Catering to the students and faculty members of San Jose State University, Spartan Superway aims to reduce congestion and parking in the city while providing an affordable mode of transportation. The concept is to travel on a suspended pod car rail system allowing the public to make it to their desired location quickly unaffected by traffic conditions, with little to no stopping. The pod car can be requested by a phone application or on-site kiosk.

5.1. Problem

Currently, the Spartan Superway team is well under way with advances in the project and is working towards a test track. The primary underlying issue the project faces is financing, creating concerns of whether or not it is economically feasible. Factors of interest are material, labor, capital and maintenance expenses. The project relies heavily on funding and public interest, but without an estimation of expenses, it is hard to justify its implementation.

5.2. Project Scope

Encompassing the financial analysis will be studies on similar projects, specifically the Portland Aerial Tram and the Morgantown Personal Rapid Transit System to help evaluate Spartan Superway. Doing so will help determine potential shortcomings and failures to be avoided. The focal point of our financial analysis will be on the test track. Under consideration that the test track will be constructed in the near future, we will also be providing a rough estimation of the completed Superway.

5.3. Limitations

San Jose is already a heavily impacted city and continues to grow both in population and infrastructure. To continue building around the campus of San Jose State University will involve a challenging and strategic design plan. Especially with anticipation of future expansion of the Superway. Currently there is limited funding, no government backing and minimal support from the public. These factors are greatly dependent on the success and extensive publicity of the test track.

The senior project team is comprised of four undergraduates, who are full time students taking upper division coursework. This limits the number of hours the team can dedicate to this project. Since this is a new project undertaken in part B of the Senior Design class, as opposed to a carry on project from part A, the team had to spend the initial few weeks laying the groundwork. This cuts away the time that could have been spent on the analytical or design section of this report.

5.4. Team and Support

The team consists of four Industrial and Systems Engineering undergraduate students; Gregory Bissell, Kyle Chiurazzi, Binal Mathew and Samer Zeid. The students are doing this project as part of the Senior Design Project under the supervision of Dr. Baruch Saeed. The team would like to thank Dr. Burford Furman, Eric Hagstrom and Ron Swenson for their support throughout the entirety of this project.

5.5. Actions Taken

In order to collect all the necessary information to put this report together, our team has held several meetings with the Spartan Superway team as well as the Industrial and Systems Engineering Senior Design Project Advisor to determine the area of focus. Once we knew what we would be estimating we set out to find as much data as possible on the several case studies as well as construction costs. This required us to contact the Portland Aerial Tram team, contractors and vendors.

5.6. Summary of findings

Many projects similar to the Spartan Superway undergo vast transformations as they move through development leading to increased costs, and as engineers we were tasked with finding and explaining the root of these causes. Through a thorough cost analysis of the Spartan Superway we were able to determine a low cost and high cost estimate of the test track as $842,100 and $1,480,600 respectively with an average of $1,162,800. This cost analysis accounts for all foreseeable factors in the construction of the test track, under the impression that there will be a minimal amount of external factors acting on the project. Morgantown and Portland have also shown us that when big improvements to infrastructure like this one are proposed, they often get tangled up in politics where everyone wants a piece of the pie. This leads to exuberant spending on unrelated expenses and beautification of the project. It also should be noted that both of the case study systems operate at a loss and that the implicit benefits of the systems outweigh the financial gains to the city.

6. Study Overview

6.1. Portland Aerial Tram

6.1.1. Introduction

Figure1: Portland Aerial Tram *Retrieved from:* http://andersonkrygier.com/projects/civic/portland-aerial-tram/

The Portland Aerial Tram is a cable car system that carries passengers from the South Waterfront District to the Oregon Health and Science University (OHSU) Campus. It spans a distance of 3,300 feet horizontally with 500 feet in elevation, and has a ridership of 10000 riders per day Monday through Friday. The OSHU staff, students and patients comprises 85% of the ridership and the remaining 15% are public riders. The initial estimate of the project was $9 million with an operating cost of $480, 000 per year and the final cost of the project was $57 million with an operating cost of $2.6 million per year. The final budget was six times over the initial forecast and therefore, it would be an ideal case study to determine the reason for the discrepancy.

This case study will provide some insight into the construction and cost estimation of a large scale transportation project. Portland Aerial Tram was selected as one of the comparable projects for the top down analysis because, it is an iconic mode of transportation that had a huge discrepancy in the initial vs final budget. The conclusions formed in this analysis could help with identifying certain risk factors and mitigating them in the construction of the Spartan Superway.

6.1.2. Analysis

According to an article[1] published in 2001 in the Oregonian, Gordon Davis, a consultant working for the university, estimated the cost to be $9 Million for construction and $480,000 per year in operating cost. Davis suggested that the tram is more viable than 10 buses which would cost $1.2 million per year to operate. There was significant pushback from the neighborhood, where the tram was being built. The residents argued that it only serves the interest of the university and does not go to downtown where the public would want to go. Therefore, promoting the tram as a public transportation and traffic alternative idea was not well received.

By January 2003, the nonprofit corporation formed to manage the aerial tram project, PATI (Portland Aerial Transportation Inc.), had decided to hold an international competition with four architectural and engineering firms. The estimate provided by PATI at that time was $17 million[2]. Later in March of the same year, another article[3] was published with a more reasonable estimate of $15.5 Million. By November, the new estimate release by PATI was in a range of $24 million to $30.2 million[4]. Pat LaCrosse, the chairman of PATI at the time, added there was a misunderstanding regarding the initial estimate. LaCrosse justified the misunderstanding by saying that the initial estimate did not include soft costs such as design, management and contingencies, and it only included the construction costs of the tram.

[5]In April of 2005, the city council passed the budget for the $40 million tram project. The new inflated cost included the $19.7 million budget for Kewit Pacific Co., the general contractor, $10 million for Doppelmayr CTEC, the company that supplies and installs the tram cars and the equipment, $3.6 million for contingencies, $2.2 million for utility relocation, street trees and streetlights, and $5 million for neighborhood improvements including pedestrian bridge and a traffic study.

[6]Within six months of the approval of $40 million budget, in October 2005, the budget was again increased to $45 million. The reason, according to Vic Rhodes the project manager for PATI, was the huge demand for steel in China and the subsequent price inflation. The revised budget also included the contingency fund of $3.7 million, which is essential for technical complexity and unexpected occurrences.

[7]Pinnell/Busch, a consultant company hired to conduct an independent risk assessment of the project, estimated the cost to increase to $50 million with a contingency of $5 million for a total cost of $55 million as of February 1, 2006. The report published by Pinnell/Busch outlined the reasons for increased cost as tight schedule with no room for unanticipated delay, construction difficulty of the unique architectural design, restricted site for the construction of upper station, complicated integration of European Tram system with American structural

system, complexities involving the installation of steel cables over highways and city streets, structural concerns regarding the tower, unanticipated problem with permits from various regulatory agencies, unanticipated operational issues, and scheduling conflicts between Doppelmayr and Kewit.

[8]The city ordinance passed on October 4, 2006 included the final budget for the Portland Aerial Tram to a total cost of $57 million including the risk assessment estimate and an additional [9]$2 million that was erroneously not included in the spreadsheet initially submitted by Kewit to the city.

The timeline and budget of the Portland Aerial Tram project over the course of its completion is shown in Figure 1 below. The cost of the tram shot up over six times the initial estimate. Over the course of 5 years, from 2001 to 2006, there were several unforeseen events that led to the inflation of budget. Mainly, the management team did not have a thorough understanding of how to undertake a project of such scale. The initial estimates were severely low, not taking into account the management costs, design costs and other soft costs that are significant in the completion of the project. There were also unexpected events such the cost of steel increasing due to high demand in the global market. The initial proposal did not include a contingency budget which, if estimated correctly, would cover unforeseen cost inflations.

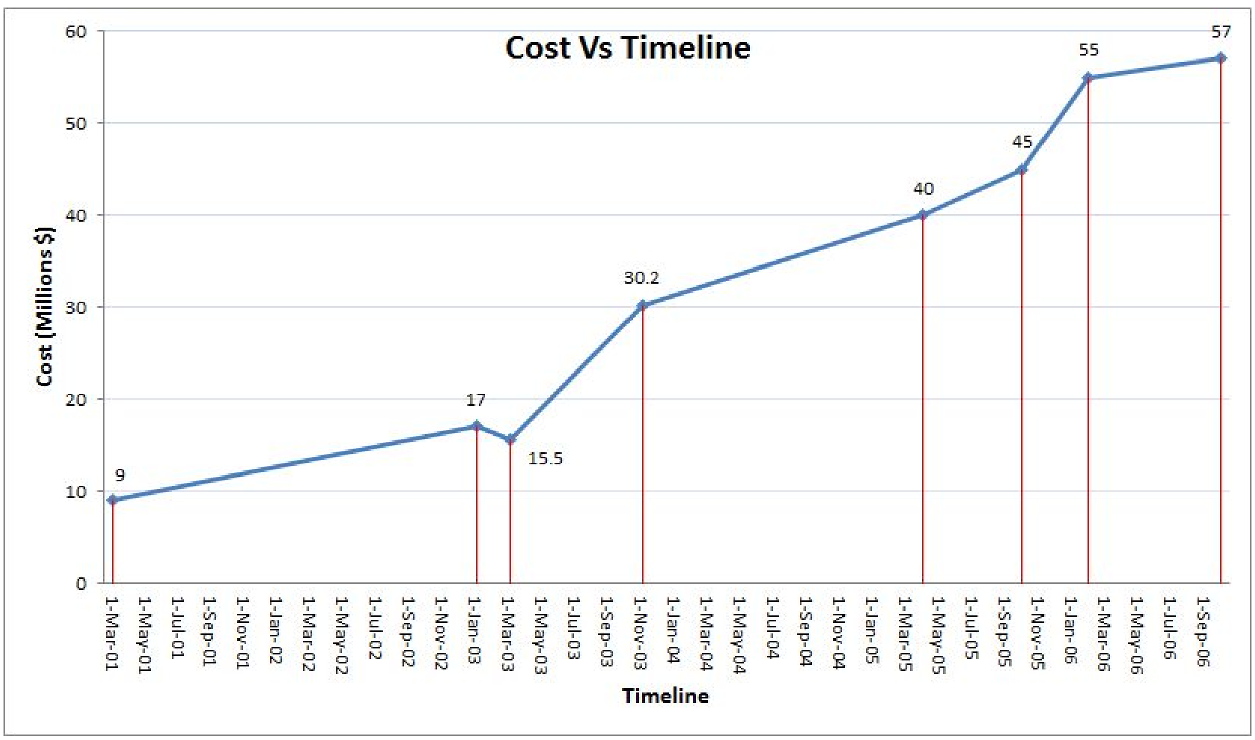

Figure 2: Budget and Timeline of Portland Aerial Tram

In addition to the management ineptitude, there were several design issues that were overlooked. Issues arose included the construction of pedestrian bridge over a highway, several neighborhood improvements and complications in combining the European tram system with American structure. These issues were addressed as the tram was being built, which added to the cost inflation. It is significantly cheaper to address the errors in conceptual design phase rather than the construction phase. The events that led to the budget inflation are outlined in Table 1 below.

Table 1: Portland Aerial Tram - Events that led to budget inflation

Date	Events	Budget
March 2001	Initial Estimate by Gordon Davis (OHSU Consultant)	$9 Million
January 2003	PATI Initial Estimate	$17 Million
March 2003	PATI Second Estimate	$15.5 Million
November 2003	PATI Estimate including soft cost, management contingencies and tram cost	$30.2 Million
April 2005	$19.7M - General Contractor $10M - Tram $3.6M - Contingencies $2.2M - Utility Relocation $5M - Neighborhood Improvement	$40 Million
October 2005	Steel price increased due to construction boom in China	$45 Million
February 2006	Pinnell-Busch Risk Assessment Estimate Contingency increased to $5M Estimated Construction Cost - $50M	$55 Million
October 2006	$2M erroneously not included by Kewitt Pacific Co.in the Risk Assessment budget submitted to city	$57 Million

6.1.3. OHSU's Perspective

The team reached out to the OHSU Transportation and Parking department and they were able to provide some insight into the cost inflation as well. According to Ryan Malzahn, Transportation Systems Manager at OHSU, the initial estimate was just for an aerial transportation system that would span a distance of 3300 feet horizontally and 500 feet vertically. Malzahn also mentioned this budget was made public early in project timeline, which made the $9 million a target used to benchmark for the actual project. The budget proposed to OHSU and the city after the feasibility study was in the range of $15 million. The $15 million budget was used for Request for Proposal (RFP) and vendor selection.

Another reason, according to OHSU, for the cost increase was design, art and use of expensive materials of the project. The final design of the tram is “iconic” compared to the initial design which incorporated “two concrete towers, square metal tower and two standard off the shelf cabins”, Malzahn added. The final design is shown in Figure1 below. Some of design and construction challenges also added to the cost increase. The cantilevered structure, which is designed to hold 1 million pounds of force 160 feet in the air, was designed with 3 inches of tolerance. In order to mitigate structural deformation due to solar heating, heat repelling paint was used for the tower. The upper station required 50 feet of footing between 2 hospital buildings, which also added to the construction cost. a

Figure 3: Portland Aerial Tram Final Design

OHSU was also able to provide the details of their annual operating budget. The budget categories and their expenses are given in Table 1 below. OHSU also clarified the reason for the discrepancy in operating budget from initial estimate of $480,000 to current budget of $2.6 million. According to Malzahn, the hours of operation, need to have the cabins staffed anytime it is open to public and other additional expenses that were missed in the initial budget along with a 50 year major maintenance replacement fund all added to the increased annual operating budget. The Portland Aerial Tram currently generates a revenue of $584,574 and has an an annual expense of $2,582,427. Therefore, it is currently operating at a loss of $1,997,853. Being a public transportation system, the main objective is to provide service than generate profit. So the loss in operation is expected of such a system. It should also be noted that, since the introduction of the tram, the growth in the Southern Waterfront District and the OHSU campus has been phenomenal.

Table 2: Annual Operating Expense of Portland Aerial Tram

Items	**Annual Budget ($)**
Salaries and Benefits	
Payroll Unclassified	43,600
Manual Payroll Adjustments	-
OPE Unclassified	13,096
Services and Supplies	
Custodial Expenses	2,000
Banking fees	6,000
Conference & Travel	-
Delivery & Freight	4,500
Event Expenses	-
Maintenance Expense	114,500
Marketing & Promotion	40,000
Misc Services	625,172
Professional Development	500
Professional Services	1,699,940
Rental Expense	250
Telecommunications	7,400
Utilities	1,000
Administrative Expenses	1,600
Laundry	758
Medical Supply	250
Minor Equipment	-
Misc Supplies	20,000
Software Purchase & Maintenance	1,800
Building Maintenance & Repair	-
Other	-
Total Operating Expense	**2,582,427**

6.1.4. Conclusion

The Spartan Superway project is very much similar to the Portland Aerial Tram. It is a futuristic mode of transportation built in collaboration with the university and the city, along with public investors. There are several factors that could lead to unforeseen costs. The test track that will be built in Phase 1 may not have to address any of the issues mentioned above, but it must be addressed in the final design. For the test track, the main focus will be on cost estimation and project scheduling. Since this will be built on private land, the safety concerns are minimal. The estimate will include the materials, labor and operating cost. These are predictable with a higher degree of confidence compared to the actual implementation from SJSU main campus to South Campus.

For the Phase 1 of Spartan Superway, which is the construction of the track from Main Campus to South Campus, there are several factors that must be studied in detail. There will be unforeseen risk factors that must be accounted for, in order to ensure the completion of the project in the given timeframe and budget. OHSU's decision to announce the initial budget of $9 million to the public before completing a detailed feasibility study led to the public outcry and project complications. According to the documents provided by OHSU, 71% of the construction cost was provided by university and the remaining funds were secured through the city and local developers.

6.2. Morgantown Personal Rapid Transit

Morgantown, West Virginia is a small city with few permanent residents, with seasonal students. Almost doubling the population during the school season. Due to this, Morgantown has been plagued with traffic issues, more precisely gridlock during peak hours of commuting between college campuses. Preventing students from reaching classes and workers from reaching jobs on time. In order to combat this issue the city sought out the help of Boeing in order to engineer a "personal rapid transit" system in the city. The personal railcar system has enjoyed great success and heavy use in the community but had a rocky start with budget coming in at over 60 million, roughly four times the initial estimated cost in 1970.

Figure 4: Morgantown Railcar

The Morgantown Personal Rapid Transit (PRT) system is a railcar system composed of 8.7 miles of rail, which combines the separate campuses of West Virginia University and Morgantown's business district. The project was first started in 1971 and was completed over the course of two separate phases in nine years, incurring approximately $120 million in cost. Initially the system was seen as a demonstration of the feasibility of a "fully automatic urban transportation system." However the system has seen great success since the initial construction and still sees use by approx. 15,000 people per day, with only forty percent government subsidization. The vehicles are electric powered, operate on a guideway, and have a minimum of fifteen seconds between vehicles. When initially built the Phase 1 system contained 5.2 miles of railway, 3 stations, 45 vehicles and one maintenance facility. During 1978-79 the system grew to 8.65 mi of rail, 71 vehicles, and 5 stations. Mean waiting time of 3.13 min, on par with predicted time from dispatching algorithm. (MPM Phase 2 impact assessment) Students average 24 rides per month, while faculty and staff average 4.8 per month and surveyed non-University residents use only 1.4 times per month, with half of the non-University residents claiming to have never used the system. One of the major issues that was encountered during the testing phase was the problem of snow and how to heat the tracks in order to melt the snow and continue operation during the winter time. The budget for this project rapidly expanded for a multitude of reasons, a few of which that should be taken into consideration are; the speed in which the project was completed, unforeseen technical problems, and political climate. Heavy use of overtime and rush to complete the project caused a heavy increase in cost.

6.2.1. Project Schedule

Budget Phases: Pre Phase 1(1973-1975) 15-20 million dollars, Phase 1(1975-1978) 62 million, Shutdown/Phase 2(1978-1979, 64 million), phase 3 "modernization" approved in 2012, part 1 coming in at 21.7 million, approved for 120 million total over three iterations.

Pre Phase 1 consisted of a guideways and stations, however only testing was being done and no service was offered to the public. During Phase 1, the stations were in service, vehicles had to be scheduled on their routes, demand responsiveness was lacking, a better method of dispatching was necessary, and the system was plagued by issues. The shutdown phase provided time for the system to be fixed and the second phase to roll out, meanwhile students had to be transported by bus back and forth between campuses. Phase 2 fixed many of the issues that were exposed with the PRT, the system became automatic and many issues with reliability were solved. In 2012 the Morgantown PRT system was approved for a 120 million dollar renovation, the first of three iterations were completed in 2015 with a visible cost of 21.7 million dollars.

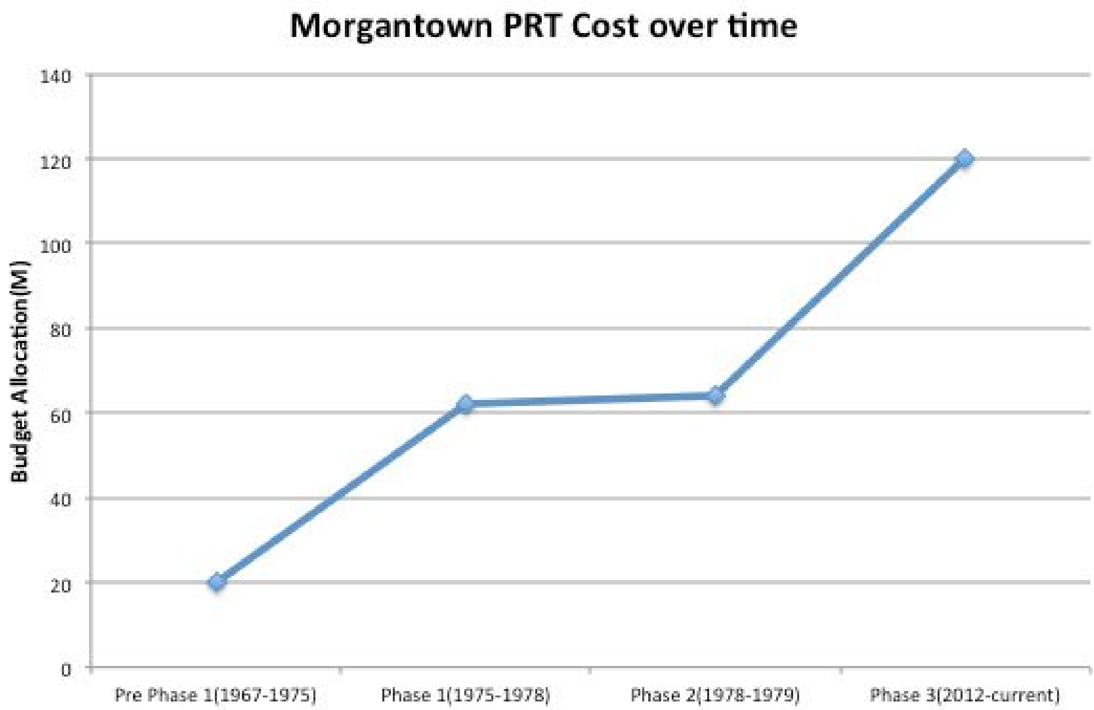

Figure 5: Morgantown Budget Timeline

6.2.2. Budget/Cost Estimation in 2017 dollars

In order to accurately represent the history of the Morgantown system, we must first understand the nature in which it came about. The Morgantown rapid transit system was first seen as a system meant to demonstrate the viability of rapid transit systems across the country and ended up becoming a political pawn used for elections in 1972. Along with being used to push political campaigns, the Morgantown rapid transit system was promised to be completed by a certain date by the candidate at the time. Now with a date looming overhead the Morgantown system was rushed to the completion of its first iteration. Taking about a decade to complete, the final price came in at about 130M dollars, which is roughly equivalent to 464M in 2017(3.4% annual inflation). Taking this into consideration and through reading some of the case studies on the subject, it can be concluded that the Morgantown case was more so a "proof-of-concept" than anything and was not constructed efficiently given the constraints.

6.2.3. Modernization

The Morgantown personal rapid transit(PRT) system was approved for updates in 2012, as the 71 car fleet was rapidly deteriorating, systems were reaching obsolescence, and the car computer systems antiquated and uncommunicative. The first phase of this series of improvements focused on the onboard computers of the pod cars and helps the control room by having the pod cars communicate their locations at points on the track. This update is meant to help the controller ease congestion and improve the availability of pod cars during peak use. The most budget intensive section of these improvements is the second phase, which is estimated at 52-54 million dollars and aims to replace the electrical equipment and automatic train control system. The pod car itself will be the focus of the last phase, as the current pod cars weigh around 5 tons each, whereas new pod cars could weigh 3.5 tons lighter

6.2.4. Activity Based Cost Model

Table 3 is a table of the activity based costing model used to estimate the proportions of the budget that were allocated in the modernization of the Morgantown PRT. The activity based cost model below can give a better idea of the expenses of running a system like this in the long term and better insight into the budget of the Morgantown PRT which is relatively hard to find.

Table 3: Morgantown ABC

Morgantown modernization Activity Based Costing model(ABC)				
Cost pools	%	cost($M)	activity per year	Allocation per unit
Assembly	20	24	72	333,333
Redesign iterations	10	12	3	4,000,000
Maint./Breakdowns	5	6	10	600,000
Existing Pod Car update	15	18	71	253,521
Pod Car replacement	50	60	72	833,333

6.2.5. Conclusion

The Morgantown PRT system is antiquated in comparison to the Portland aerial tram and Spartan Superway, however is useful in forecasting unanticipated costs. Major problems that affected the Morgantown system such as the necessity of a heated track that drove up costs, will cease to affect the Spartan Superway on the basis on radically different design. The Spartan Superway system is however being built from scratch and the purpose of the test track is to work out any design flaws that will increase costs when a full scale system is implemented at a later time.

6.3. Cost Estimation - Spartan Superway Test Track

6.3.1. Introduction

The engineers of Spartan Superway are well underway with a full-scale test track. Through the previous phases of their most recent intermediate sized track, they demonstrated a two-path guideway for simulating arrival, pick up and travel. This simulation helped test guideway stability, the load of the cabin, suspension system, electrical interfaces for charging the solar panels and material choice. The guide rails extending the length of 70’ was able to support 300 pounds of force, costing a total of $1,907.

Having a design layout for the full-scale test track almost finalized, the team is now faced with the guideway cost estimates. It is imperative this project has been properly budgeted before construction or it could consequently affect the time and quality of construction. This cost estimate will help reflect the feasibility of the Spartan Superway test track project and how much funding will be needed. Assumptions have been listed so numbers can be manipulated at a future time. Some costs such as solar panel, pod car and material cost have been provided by the Spartan Superway team.

6.3.2. Analysis

The total cost estimate breakdown of the test track will be calculated by considering the following costs:

- Guideway rail material
- Material bending
- Milotek vertical columns material
- Suspension system
- Hardware
- Solar panels
- Electrical components
- Pod car
- Cement
- Tools/machinery
- Overhead

For the test track, three pod cars will be used to demonstrate the functionality of the track. This track will be running 24 hours a day and observed by both the engineers and the public. The track will be located at 1555 S 7th street, near South Campus of SJSU. This two-way track will have two stations. One station will be on the ground level and the other will be elevated, accessible by stairs. The max height of the track is 6.1 meters. Other important measurements used for test track cost estimations are as follows: distance between the pod cars is 2 meters, distance between columns is 10 meters, dimension of column is 0.5x0.5 meters and the radius of the curve of the test track is 10 meters.

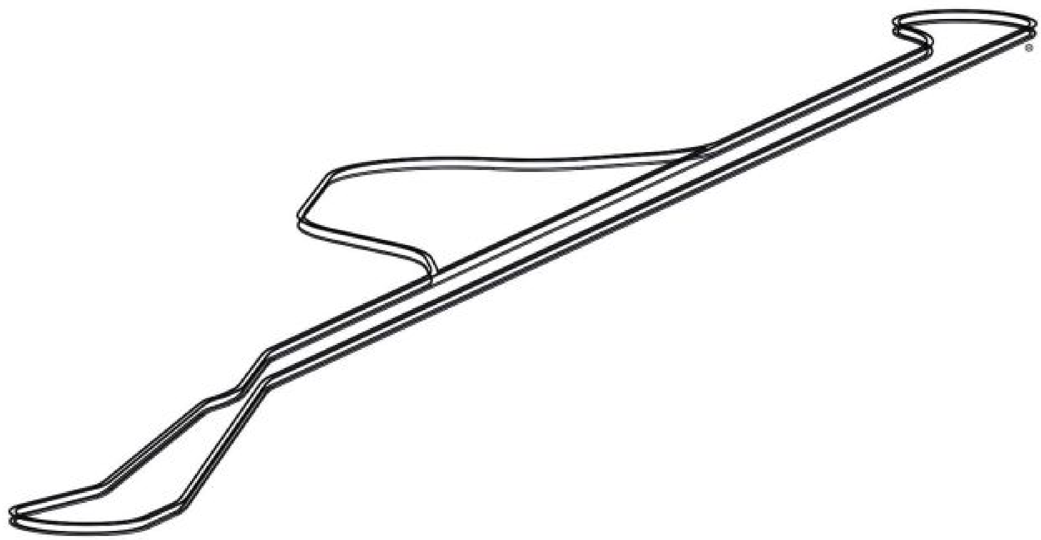

Figure 6: 3D model of test track (from civil engineering team)

For the final track an estimated 15 pod cars will be available for service. Each pod car is capable of occupying 4-6 passengers with dimensions of 3(L)x2(W)x2.5(H) meters. The design is also made to be wheelchair accessible and capable of transporting bicycles. The estimated total cost of a pod car is $100,000 including material and electrical components, air conditioning and other technology.

Figure 7: Proposed Bogie Cart System

6.3.3. Cost Assumptions

6.3.3.1. Track Estimation (Columns):

The number of columns needed for the test track has not yet been defined. To estimate the number of columns needed, the team referenced the design layout of the test track provided by the Civil Engineering team and google maps to approximate the dimensions of the track. The straight for one side of the track was estimated to be 365 feet long and considering there are two sides, the straights accounted for 730 feet of track or 222 meters. With the prediction that there will be a column for every 10 meters of track, 23 columns will be needed for the guideways straight sections. The ends of the guide way form a loop with a 10 meter radius curve. The calculated circumference of the curve is 203 feet and dividing that by two since the guide way does not go around in a full loop and each end is approximately 102 feet or 31 meters. The end loops would need three columns each side plus an additional one used as reinforcement for the forces being exerted going around the curve. The tracks pick up station loop was estimated at 135 feet long or 42 meters needing five columns. For the 295 meters of track there is a total of 32 columns predicted to be needed for the test track.

Milotek vertical columns is the structural support that Spartan Superway has selected to be the vertical columns of the guideway. This is a sheet metal thickness of 3mm to 8mm, using 5mm as the thickness for project assumptions.. Harshavardhana Ashok Kumar Reddy, who wrote the study *Building a Supply Chain Network for Manufacturing of Steel Columns,* quoted the price for domex steel from a supplier in Iowa to be $584.32/sheet. The dimension of the sheet is 50 by 315 inches (w*l), weighing 400 lbs. Totaling the labor, material, and overhead costs, the estimated cost for the Milotek column design would be $909.95 per column.

6.3.3.2. Guide Rails and Support:

For the supports (hanger brackets) of the test track, Milotek columns and metal tubing are being used. It was assumed that there is 14 feet of tubing being used per unit, with 32 units total and it is 4x4 inch tubing with a thickness of 0.25’’. With these estimates, it would cost $175-$300 per unit. Another assumption is that ¾ in diameter and 3” long grade 8 bolts would be used. At $3.25 per bolt (quoted from McMaster) and 50 bolts per unit would cost assembly hardware roughly $100-$300 per unit. Assembly of the support was estimated at 3 hours per unit and at a wage of $125 an hour, including welding, costing $375-$600 per unit.

The guide rails for the track was assumed to use four 4” x 3” x 0.25(thick) tubes. Per unit, these tubes are 10 meters long with 32 units costing an estimated $400-$685 per unit. Hardware for the guide rail was estimated at $100 per unit. Construction costs for the guide rail such as material bending and setup are as follows: Construction for the straight sections are estimated to cost $200-$400 per unit with 20 units, the curved sections will cost more due to material bending and are estimated at $600-$1000 per unit with 18 units and various sections are considered to be more intricate crafting estimated at $800-$1200 per unit with 4 units. Total cost estimates can be seen in table below.

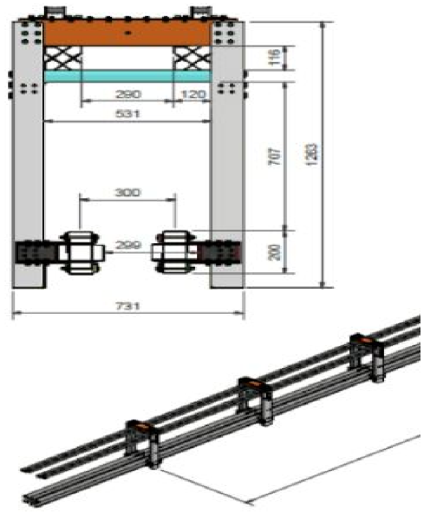

Figure 8: Guide rail and hanger bracket

6.3.3.3. Suspension:

The Spartan Superway team is still modifying their current suspension system. The intermediate scaled tracks suspension was a success, but through testing have found modifications to implement into the full scale track. The team was not able to retrieve a cost total for the intermediate track, so assumptions had to be made for a cost estimate of the suspension for the test track. The cost estimate for each suspension system is $6,000-$15,000 with three suspension systems. For assembly costs and labor, it was predicted that a three man team was needed with wages of $200 per hour and 1.5 hours total per suspension system.

6.3.3.4. Electrical:

The wiring assumed needed for this project was 0 gauge 600 volt wire. With a predicted 4,500 feet of wire needed for the track at $4 a foot would cost a total of $18,000.

6.3.3.5. Cement:

For a project of this scale, a lot of concrete is needed. Not only do the Milotek columns need to be filled, which will require a cement pump truck, but the footing for the vertical columns need to be filled as well. Ready mix cement cost $93 per cubic yard, averaging $4.25 per square foot. To fill a column would cost $85 dollars of cement with 32 columns, equaling $2,720 for the columns and filling the guide rails would cost $8,200 total. The footing dimensions is 3x3x1 meters (given by SJSU civil engineers students), which comes out to $35,032 of cement cost. The total cost estimate for concrete is $46,000.

6.3.3.6. Tools and Machinery:

A concrete pump truck will be needed to fill the vertical columns. These cost trucks are priced at $120-$200 per hour. The truck will be needed for an estimated 64 hours costing a total of $7,680 for the low cost and $12800 for the high cost.

A 30' or higher crane will be needed for lifting and moving the guideway columns and rails. A carne cost roughly $2,000-6,000 a month for the size needed for this project. Estimating that the crane will be needed for 3 months, the total crane cost will be $6,000 for the low cost and $18,000 for the high cost.

A bobcat with a auger attachment will be needed to drill the 32 holes for the vertical columns. A bobcat alone cost $1,200-2,300 a month plus an additional $500-1,800 a month for the auger attachment. It will take an estimated 2 months of rental use, costing a low estimate of $3,400 and a high estimate of $8,200.

A moving semi-truck will be needed for transportation of materials such as the vertical columns. Leasing a used semi truck cost $800-1,600 a month and insurance runs at about $900 a month. Estimating a 3 month semi-truck rental would cost a low of $5,100 and a high of $7,500.

6.3.3.7. Overhead:

Due to stipulations dealing with managing and contract work the team has decided to set the overhead cost at 27% of total cost.

6.3.3.8. Stations:

Though the the stations for the full scale track were estimated to be a low of $350,000 and a high of $1.5 million, we figure the stations for the test track were not going to be to elaborate. A standard metal stairway up to a small shed like structure would suffice and be relatively cheap to construct. Though it does need to be sturdy and someone presentable to the public so it has been given a $20,000-50,000 budget depending on how elaborate of a station the team wants to build.

Table 4: Total test track cost estimate

Types of Costs	**Number of Units**	**Low Cost Estimate (dollars)**	**High Cost Estimate (dollars)**	**Average (dollars)**
Milotek Vertical Columns (steel)	32	900	1,200	33,800
Guide Rails material		12,800	22,000	17,400
Guide rails construction and bending for straight sections	20	200	400	6,000
Guide rails construction and bending for curves	18	600	1,000	14,400
Guide rails construction and bending for various	4	800	2,000	5,600
Support (hanger brackets) with labor		17,600	28,800	23,200
Suspension system	3	6,000	15,000	31,500
Hardware		6,400	19,200	12,800
Electrical		18,000	22,000	20,000
Solar		200,000	350,000	275,000
Tools and Machinery		22,200	46,500	34,400
Pod Car	3	85,000	150,000	352,500
Cement		46,000	60,000	53,000
Stations	2	20,000	50,000	35,000
Total cost		**663,100**	**1,165,900**	**914,500**
Total cost + overhead (27% of total cost)		**842,100**	**1,480,600**	**1,162,800**

6.3.4. Conclusion

Having a cost estimate of the test track, the Spartan Superway can now look at the feasibility of the project and have a figure to refer to as a goal for funding. It is important to note that these cost estimates are based off of assumptions and certain cost may have not been accounted for such as supply chain cost, some transportation costs, environmental costs, waste cost, city planning (such as having to close off roads for transportation), tools, machinery and any other unforeseen costs. The analyses of the Portland aerial tram and Morgantown tram show examples of unforeseen costs for projects of relative scale and should be considered in the development of the Spartan Superway test track. The total low estimated cost of the test track is $842,100 with the high estimate of $1,480,600 and average estimation of $1,162,800. If the design and planning phases are executed methodically, it is plausible to achieve the low estimate. It is recommended that the Spartan Superway team use estimates as a fundamental guideline because being associated with San Jose State University may present discounts and donations for the project.

6.4. Incentives

6.4.1. Tax Rebate

The city of San Jose (SJC) offers a special rebate on use taxes for the purchase of materials and equipment. A use tax is essentially a sales tax that is levied on goods purchased from outside of the state and where no tax was collected on in the state the purchase was made. What the city of San Jose is able to do is refund a rebate up for 20-30% of the allocated tax funds.[15] The way this rebate works is after joining the SJC use tax program, any purchase eligible has the use tax allocated directly to the city of San Jose; and from there, members will receive the rebate of 20-30% directly from the city.

There are a couple qualifying steps before purchases are eligible for rebate. The first step involves contacting the city and joining the program before the purchases are made. Secondly, the SuperWay team would have to remit the use tax that would have been going to the State of California. San Jose city would be able to assist the team in the process, including obtaining a Direct Pay Permit (DPP) for the city. At the end of the reporting quarter and after the use tax has been verified with the state, members would receive the rebate within 45 days.[15]

6.4.2. Funding/Subsidies

Funding for public transportation systems come from various avenues at both the state and federal level. For most public transportation, the farebox recovery is generally a major source of income. Research by the Washington Department of Transportation (DOT)[10] allows us to get a general understanding of how much of the operating costs a public transit system can recoup with fare pricing. For example, the data shows that the BART system was able to generate almost 66%.

One source of funding for public transportation comes from California's Transportation Development Act (TDA), established in 1971. This fund is broken into two funds, the Local Transportation Fund (LTF) and the State Transit Assistance Fund (STA). The LTF is generated by a ¼ cent of the general sales tax that is collected statewide. The STA is generated by the statewide tax that is imposed on diesel fuel purchases.[11] There are two main guidelines for gaining funding for transportation projects using the TDA. The first is the project must be able to maintain a minimum of a 20% farebox ratio in an urbanized area, or 10% in a non-urbanized area. In addition to this, there must be a farebox plus local support to operation cost ratio of 20% in urbanized, and 10% in non-urbanized locations.

Once funds have accumulated for the year, there is a three step process that is used to; apportionment, allocation, and payment. Apportionment is the first step and is used to determine how much money each area in the state will be given. Allocation is where the Transportation Planning Agencies determine which claimants will receive the money. Finally, the payment is made. In fiscal year (FY) 2011/2012, the LTF and STA accumulated $1,323,391,504 and $416,254,131, respectively. Of this, the Santa Clara area was allocated $85,803,754 for FY 2011/2012.[11] The Santa Clara County Transportation Planning Agency then decides which claimants receive how much money, if any at all.

Another grant that exists in the state of California is the Sustainable Transportation Planning Grant program that is provided by CalTrans. For FY 2017/2018, there was over $9M to be distributed.[12] The main fund is separated into two fund categories, the Strategic Partnerships grant, and the Sustainable Communities grant. These grants are strictly for research and planning of sustainable transit systems, not to be used for the actual construction.

The Strategic Partnerships grant is primarily administered by the Federal Highway Administration. There is a grant minimum of $100,000 required here and a maximum of $500,000[13]. The purpose of this grant is to be used for transportation planning studies in partnership with CalTrans that are used with local, regional, or statewide impact. There are two necessary measures to apply for this grant, the University must apply as a sub-applicant with a regional transportation authority, and there must be a minimum local match of 20%.[13]

The Sustainable Communities grant may be a better choice for the grant. It provides the same minimum and maximum grant amount as the Strategic Partnership grant but only requires an 11.47% local match on funds.[13] There is also an easier path to application as the university would be able to apply for the grant as a sub-applicant of the city or county, without the need of convincing a regional transportation authority..

In addition to the funding provided for the actual planning and studies, indirect costs can be recouped as well. Items such as paper, office supplies, computer rental, etc are all considered indirect if they aren't tied to a specific activity. Using an Indirect Cost Allocation Plan (ICAP) the Superway team would also be able to be reimbursed for these items. There are also other eligible items that would be reimbursable; this includes data gathering/analysis, consulting costs, focus groups, community surveys, and conceptual designs or drawings.[13] All of this would be highly beneficial to the Superway team.

On the federal level, the Federal Transportation Authority (FTA) provides a grant for both small starts and larger new starts. The FAST program most recently had over $2.3B to be allocated to various projects around the country.[14] The SuperWay, if under $300M total, would qualify under the small start category; this paves the way for up to a $100M grant. If the total project cost is estimated over $300M,

The approval process has two main stages with the first consisting of FTA approval of the plan itself. In this stage the FTA will conduct an environmental review, comb through alternatives to the proposed idea, and determine what the local preferred alternative is. The next stage consists of the FTA conducting a rating of the overall plan using the FAST criteria. These criteria include environmental benefits, mobility, potential congestion relief, cost effectiveness measured by cost per trip, and finally a confirmation of proper local funding to complete the total project.[14]

To receive funding from the president of the FTA there are an additional number of qualifiers. The main one being the "readiness" of the project itself. The project's overall rating based on the FAST criteria mentioned above is taken into account. "The amount of available funds versus the number and size of the projects in the pipeline."[14] To finally receive payment the last few qualifications include having an overall "medium" rating, meet project readiness requirements, and complete the planning, development, and environmental review processes.

6.5. Scheduling

6.5.1. Introduction

The goal of scheduling was to determine the minimum time required to build the track connecting San Jose State University to the south campus. One major assumption is that the staking has been completed. Staking is essentially a survey conducted to see what, if any, obstacles will impede the construction. For example, common issues would be gas pipelines, electrical lines, or fiber optic internet routing. A second assumption is made in regards to the "days" in the subsequent linear program and scheduling. Each day is considered one eight hour work day. In addition to the scheduling of the construction project, testing of the system will require a minimum of 90 days to complete once the track has been constructed.

The route is approximately 1.5 miles according to Google Maps. To start off, the 1.5 mile route was split into three approximately equal sections. Furthermore, each section was then divided to consist of three major construction jobs. The first was digging the holes, which would then be used for installation of the support columns. These holes will be dug approximately every 10 meters and will require an estimated 27 days per section; meaning three holes per work day. The next major component will be the column installation, which will require approximately 80 days plus an additional week for the concrete to set. This equates to one column per day, every 10 meters, over the approximate 800 meters in each section. Once the columns are installed, the next phase is the installation of the guideway which is estimated at 60 days. Finally, the boarding and landing platforms are the last portion of the project.

6.5.2. Analysis

To find the shortest time frame in which the track can be built, a linear program needed to be formulated. The high-level tasks involved in the construction amounted to 10 separate tasks. The next step was determining which tasks had precedence and assigning them an earliest start date. The starting task is task #1 is digging the holes for section one. Once that job is completed the next task can either be task #2, installing the columns, or digging the holes in section two. The predecessors for the column tasks are the their respective digging tasks and the prior sections column installation, if applicable. For the guideway installation there are two preceding tasks, which are their respective column installation tasks and the installation of the prior sections guideway, if applicable. These relationships are shown below in the network diagram below in Figure 9.

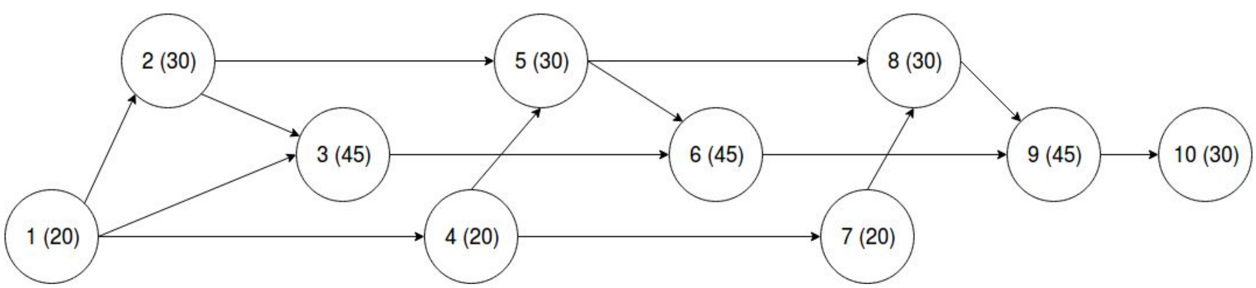

Figure 9: Network Diagram of Construction Tasks

Each circle, or node, in the network diagram represents one construction task denoted by the numbers one through ten. The numbers inside the parenthesis represent the estimated number of days the respective tasks will take to complete. A table was created to further clarify the relationships between nodes and their predecessors below in Table 1.

Table 5: Network Information and Relationships

#	**Task**	**Predecessor**	**Duration (Days)**	**Earliest Start**
1	Dig Holes S1 (Section-1)	---	27	---
2	Install Columns S1	1	87	t_1
3	Install Guideway S1	1, 2	60	t_2
4	Dig Holes S2	1	27	t_1
5	Install Columns S2	2, 4	87	t_4
6	Install Guideway S2	3, 5	60	t_5
7	Dig Holes S3	4	27	t_4
8	Install Columns S3	5, 7	87	t_7
9	Install Guideway S3	6, 8	60	t_8
10	Boarding & Landing Platform	9	60	t_9

The objective function in this linear program is to minimize the total time elapsed, in days, from the starting task to the final task. Constraints are determined by the relationships between the task in question and any predecessor tasks that must be completed prior to the current task being started. In task three for example, the installation of the guideway requires that the holes have been dug and the installation of the columns has been completed. This indicates that the absolute earliest start time for task three is when both task one and two have been completed, as reflected in the constraints. The complete formulation is located in the appendix.

```
Global optimal solution found.
Objective value:                              408.0000
Infeasibilities:                              0.000000
Total solver iterations:                             3
Elapsed runtime seconds:                          0.09

Model Class:                                        LP

Total variables:                   10
Nonlinear variables:                0
Integer variables:                  0

Total constraints:                 15
Nonlinear constraints:              0

Total nonzeros:                    30
Nonlinear nonzeros:                 0
```

Variable	Value	Reduced Cost
T10	348.0000	0.000000
T1	0.000000	0.000000
T2	27.00000	0.000000
T3	114.0000	0.000000
T4	87.00000	0.000000
T5	114.0000	0.000000
T6	201.0000	0.000000
T7	114.0000	0.000000
T8	201.0000	0.000000
T9	288.0000	0.000000

Row	Slack or Surplus	Dual Price
1	408.0000	-1.000000
2	0.000000	1.000000
3	87.00000	0.000000
4	0.000000	0.000000
5	60.00000	0.000000
6	0.000000	1.000000
7	0.000000	0.000000
8	27.00000	0.000000
9	0.000000	0.000000
10	0.000000	0.000000
11	0.000000	1.000000
12	60.00000	0.000000
13	27.00000	0.000000
14	0.000000	1.000000
15	0.000000	1.000000

Figure 10: Lingo Linear Program Results

The following results are the output of a linear program solving software, Lingo. The objective value shown above is the minimum number of days required to complete the track from start to finish. In our case, the optimal solution for this minimization problem is 408 days from start to finish. If the project is to be done sequentially from task one through ten, the total time required would be 582 days; there is significant time and cost savings using the proposed optimized model. Adding 90 days for testing of the completed track brings the totals up to 498 days and 672 days for the optimized and sequential figures, respectively.

Looking at the 'value' column in the Lingo output shows us the timeline of each task. Each variable indicates the task it is referencing. For example, t_6 shows a value of 201. This 201 means the earliest start time for task six would be 201 days after beginning the project. This is in stark contrast to a sequential start time of 288.

The slack or surplus in these results tells us if the constraint is binding or not. If the slack or surplus value is equal to zero, then the constraint is satisfied as an equality. If the task has zero slack that means if it is delayed at all, then the project will be delayed by the value of the dual price. On the other hand if there is a slack value that means if those specific tasks are delayed than the overall project will not be delayed. For example, task four is denoted by the constraint on row five in the Lingo output. The slack of 60 indicates that the hole digging task for section two of the project could be delayed by 60 days with no effect on the duration of the project.

The dual price, also known as the shadow price, is the last major indicator of the linear program. Dual price shows how the value of the objective function is changed should one unit be added to it's respective constraint. Looking at row two, we can see that there is zero slack and the dual price is exactly one. What this indicates is that for each day this task is delayed it will result in an additional day added onto the objective function.

6.5.3. Conclusions

By dividing the route into thirds and distributing three main identical tasks per section we were able to formulate an optimization problem. The linear program shows that the track connecting San Jose State University to the south campus can be done in an optimal fashion. A traditional approach involving proceeding from each task sequentially is significantly longer, at 672 days, versus the optimal solution indicating 498 days; testing for 90 days is included in these numbers. Conducting sensitivity analysis on the linear program allowed us to determine which constraints are critical to the project and have a direct effect on the total duration of the project.

7. Recommendation

The team decided to do a top-down analysis as well as a bottom-up analysis for the Spartan Superway project. To perform a top-down analysis the team looked at comparable systems that are university subsidized, public transportation systems. One such project was the Portland Aerial Tram, designed and built primarily for the Oregon Health and Science University students and staff. Another similar project was the Morgantown Rapid Transit System, which was designed to connect the multiple campuses of West virginia University with the Morgantown Business District. The investigation into these projects gave a better understanding of unforeseen risk factors and how they could affect the project budget and timeline. Next, the team decided to do a bottom up approach in estimating the cost of the Spartan Superway test track and developing a construction schedule for Phase 1. The goal of this approach was to identify the target cost and timeline associated with bringing this project to reality.

The Portland Aerial Tram and Morgantown PRT system gave an insight into the factors that could potentially affect the completion of the project within budget. As shown in Figure 1 and Table 1, the Portland Aerial Tram budget skyrocketed from initial estimate of $9 Million to final cost of $57 Million. The factors that contributed to the cost inflation include not anticipating the soft costs, not including the cost of tram in the initial budget proposal, utility relocation, neighborhood improvement and international factors that affect raw material cost. As with any engineering project it is imperative to design in a way that minimizes construction cost and maintenance cost. Even though this paper did not evaluate the design of the projects studied, it must be noted that the design choices such as the 1 million pounds of tension being held by the towers and heat reflective paint for the towers added to the higher final cost. The construction of the Morgantown PRT system also presented challenges that led to cost increase. The poor design of the tracks led to design alteration after construction to eliminate ice from the tracks. The choice of the management team to finish the construction in a tight schedule even with overtime pay also contributed to the increased budget.

The takeaway from these two case studies are that there will be unexpected factors that could affect the timely completion of the project. It is nearly impossible to eliminate all adverse effects prior to the start of construction, but a well thought out plan could mitigate major problems and have a contingency for unexpected events. In addition to the risks identified from the Morgantown PRT and Portland Aerial Tram case studies, there are other factors that could be location specific to California and specifically San Jose. One such issue is the flood that happened in Downtown San Jose in March, 2017. Another issue that may not have been a major concern for Morgantown and Portland is earthquake. Since San Jose is very close to the San Andreas fault, the regulatory authorities may require additional reinforcement for the structure. Along with these, the standard construction procedure in California requires Environmental

Impact Study and Geological Survey, which could cost up to millions of dollars depending on the magnitude of the project and study.

The bottom-up approach for this project focused on the Cost Estimation and Project Schedule. The cost estimated in this paper is for the test track, which is estimated between $840,000 to $1.7Million dollars. This estimate is based on several assumptions that are outlined in detail in *section 6.3, 'Cost Estimation - Spartan Superway Test Track'.* Although the amount specified has been estimated based on independent research and experience, the itemized list is critical in estimating the cost for the test track. The worksheet developed to estimate the cost can be updated with more accurate numbers when the Spartan Superway team gathers actual estimate from contractors and develop a detailed Bill of Material (BOM).

The schedule developed as part of bottom-up approach is for the Phase 1 of the project which connects the main SJSU campus to the South Campus. The assumptions used to generate the schedule are detailed in Section 6.5. The schedule developed is at a intermediate level which could be further broken down into lower level as more information is gathered about the construction schedule.

Since the major funding of this project will be from government subsidies and university funds, an exploratory research into the government incentive programs is also included in this paper in Section 6.4. This not an exhaustive list, but it goes to show the different programs available for sustainable transportation solutions and public transportation.

8. Appendix

8.1. Lingo Linear Program Model

t_i = earliest start time for task i

$t_i >= 0$

$$MIN=(t_{10}-t_1) + 60;$$
$$t_1 + 27 <= t_2;$$
$$t_1 + 27 <= t_3;$$
$$t_2 + 87 <= t_3;$$
$$t_1 + 27 <= t_4;$$
$$t_2 + 87 <= t_5;$$
$$t_4 + 27 <= t_5;$$
$$t_3 + 60 <= t_6;$$
$$t_5 + 87 <= t_6;$$
$$t_4 + 27 <= t_7;$$
$$t_5 + 87 <= t_8;$$
$$t_7 + 27 <= t_8;$$
$$t_6 + 60 <= t_9;$$
$$t_8 + 87 <= t_9;$$
$$t_9 + 60 <= t_{10};$$

END

8.2. Portland Aerial Tram Annual Budget Sheet

Details	JUN-16 Actual	JUN-16 Budget	JUN-16 Variance$	JUN-16 Variance% Detail	YTD Actual	YTD Budget	YTD Variance$	YTD Variance%	Annual Budget
Operating Revenue									
Sales/Services/Other									
Non-Medical Sales/Services	$81,944	$47,381	$34,562	72.9%	$719,263	$568,574	$150,689	26.5%	$568,574
Transportation Sales	225	-	225	0.0%	225	-	225	0.0%	-
Sales to Foundation	-	-	-	0.0%	3,505	2,500	1,005	40.2%	2,500
Internal Sales	945	1,125	(180)	(16.0%)	10,395	13,500	(3,105)	(23.0%)	13,500
Total Sales/Services/Other	**$83,114**	**$48,506**	**$34,607**	**71.3%**	**$733,388**	**$584,574**	**$148,814**	**25.5%**	**$584,574**
Internal Transfers									
Misc Transfers	-	-	-	0.0%	($19,615)	-	($19,615)	0.0%	-
Total Internal Transfers	**-**	**-**	**-**	**0.0%**	**($19,615)**	**-**	**($19,615)**	**0.0%**	**-**
Total Operating Revenue	**$83,114**	**$48,506**	**$34,607**	**71.3%**	**$713,773**	**$584,574**	**$129,199**	**22.1%**	**$584,574**
Operating Expense									
Salaries and Benefits									
Payroll Unclassified	$3,917	$3,694	($223)	(6.0%)	$47,624	$43,660	($3,963)	(9.1%)	$43,660
Manual Payroll Adjustments	-	-	-	0.0%	(2,371)	-	2,371	0.0%	-
OPE Unclassified	1,423	1,127	(296)	(26.3%)	16,792	13,096	(3,696)	(28.2%)	13,096
Total Salaries and Benefits	**$5,340**	**$4,821**	**($519)**	**(10.8%)**	**$62,045**	**$56,757**	**($5,288)**	**(9.3%)**	**$56,757**
Services and Supplies									
Custodial Expenses	-	$167	$167	100.0%	-	$2,000	$2,000	100.0%	$2,000
Banking fees	412	500	88	17.7%	51,564	6,000	(45,564)	(759.4%)	6,000
Conference & Travel	6,179	-	(6,179)	0.0%	11,694	-	(11,694)	0.0%	-
Delivery & Freight	116	375	259	69.1%	8,292	4,500	(3,792)	(84.3%)	4,500
Event Expenses	12	-	(12)	0.0%	73	-	(73)	0.0%	-
Maintenance Expense	12,690	9,542	(3,148)	(33.0%)	157,178	114,500	(42,678)	(37.3%)	114,500
Marketing & Promotion	3,048	3,333	285	8.6%	17,723	40,000	22,277	55.7%	40,000
Misc Services	556,563	625,172	68,609	11.0%	557,520	625,172	67,652	10.8%	625,172
Professional development	50	42	(8)	(20.0%)	500	500	0	.0%	500
Professional Services	202,298	147,456	(54,842)	(37.2%)	1,756,270	1,699,940	(56,330)	(3.3%)	1,699,940
Rental Expense	-	21	21	100.0%	6,057	250	(5,807)	(2323.2%)	250
Telecommunications	731	617	(114)	(18.5%)	7,403	7,400	(3)	(.0%)	7,400
Utilities	-	83	83	100.0%	-	1,000	1,000	100.0%	1,000
Administrative Expenses	186	133	(53)	(39.5%)	4,733	1,600	(3,133)	(195.8%)	1,600
Laundry	-	63	63	100.0%	231	758	527	69.5%	758
Medical Supply	1,231	21	(1,210)	(5809.7%)	1,746	250	(1,496)	(598.4%)	250
Minor Equipment	-	-	-	0.0%	4,231	-	(4,231)	0.0%	-
Misc Supplies	-	1,667	1,667	100.0%	2,333	20,000	17,667	88.3%	20,000
Software Purchase & Maint	170	150	(20)	(13.3%)	3,967	1,800	(2,167)	(120.4%)	1,800
Building Maintenance & Repair	9,990	-	(9,990)	0.0%	184,203	-	(184,203)	0.0%	-
Other	(151)	-	151	0.0%	(440)	-	440	0.0%	-
Total Services and Supplies	**793,524**	**$789,341**	**($4,182)**	**(.5%)**	**$2,775,281**	**$2,525,670**	**($249,611)**	**(9.9%)**	**$2,525,670**
Total Operating Expense	**798,863**	**$794,162**	**($4,701)**	**(.6%)**	**$2,837,326**	**$2,582,427**	**($254,899)**	**(9.9%)**	**$2,582,427**
Net Income/(Loss) from Operations	**'15,750)**	**($745,656)**	**$29,906**	**4.0%**	**($2,123,552)**	**($1,997,853)**	**($125,700)**	**(6.3%)**	**($1,997,853)**
Total Net Income/(Loss)	**'15,750)**	**($745,656)**	**$29,906**	**4.0%**	**($2,123,552)**	**($1,997,853)**	**($125,700)**	**(6.3%)**	**($1,997,853)**

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