New York Tappan Zee Bridge
Economic, Environmental, and Social Analysis

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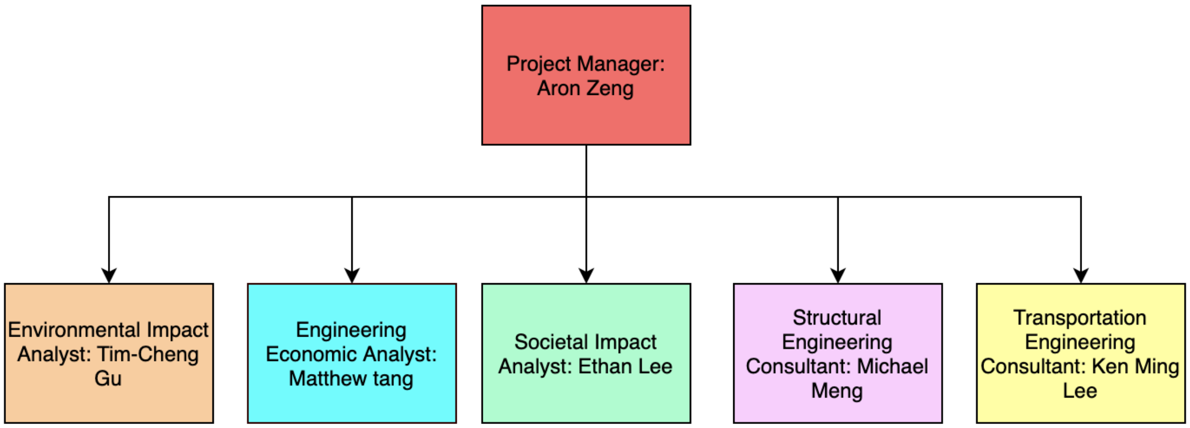
1 Contributions

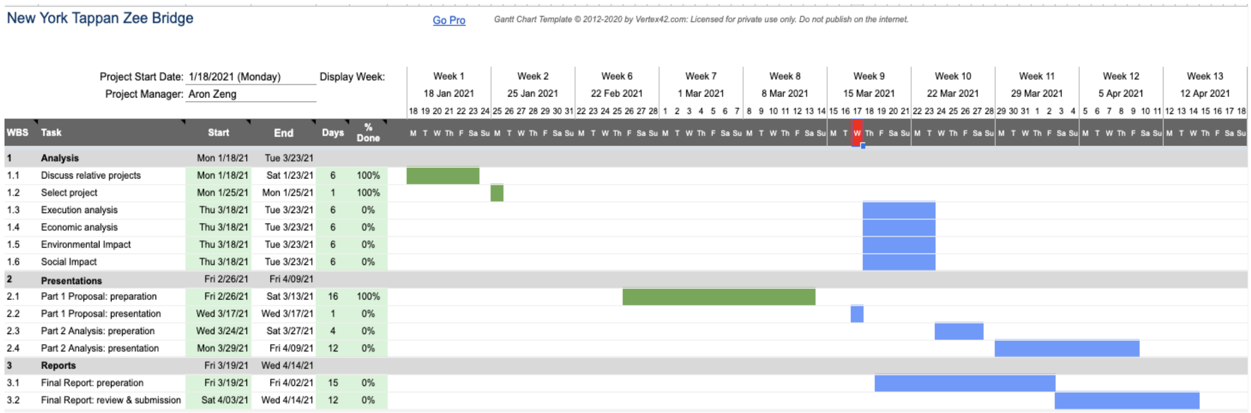
1.1 Team Organization



Figure[1]: Group Organization

As the project manager, Aron Zeng is responsible for overlooking the entire project, making sure all deadlines are met, and coordinating between stakeholders. Tim-Cheng Gu is our Environmental Impact Analyst, who is responsible for performing environmental assessment for the project and offering analysis on the environmental impacts. Matthew Tang is the Engineering Economic Analyst. He is responsible for calculating and analysing the costs of the projects, the Benefit-Cost ratio, as well as performing other financial analyses that would ensure the success of the project. As the Societal Impact Analyst, Ethan Lee will perform analysis on the social impacts of the project. Michael Meng is our Structural Engineering Consultant. He is responsible for structural analysis for the proposed solutions. Ken-Ming Lee is our Transportation Engineering Consultant. His role is to help the team to choose the best solution to reach the traffic throughput target as well as supporting the public transit needs.

1.2 Project’s Work Plan



Figure[2]: Work Plan Gantt Chart

The gantt chart shows the project life cycle. The start of the project is on January 18 and the end is on April 14 where the final report must be submitted by. The deliverables are broken down into three categories as follows. There is an analysis, presentations, and a reports category. The project begins with discussing relative projects and selecting a project before January 25. The project is resumed on Feb 25 to prepare for the part 1 proposal presentation. The part 1 proposal presentation is on March 17, and then right after this, work is started on conducting the execution, economic, environmental and social impact analysis for the part 2 presentation. At the same time, drafting of the final report begins which involves writing up the part 1 and part 2 presentation information into the report. The part 2 analysis presentation was completed on March 30, and the final report was submitted before April 14.

1.3 What does this report hope to accomplish? Who will benefit from this report?

This report provides a proposal and analysis for the New York Tappan Zee bridge project. This will benefit government agencies looking to gain insight into the decisions made in the development of the bridge as well as provide information to the public regarding analysis on the financials, environmental, and social impact of this bridge project. This report would also be a great case study for the development of future bridge projects.

2 Summary

2.1 Purpose

This report is intended to provide a detailed outline of the planning and analysis conducted for the New York Tappan Zee bridge project. This involves exploring the background and motivation for the project, as well as discussing the objectives and alternative options. Furthermore, detailed economic, environmental, and social analysis will be conducted on the alternatives. Based on the results, there will be a suggested course of action and recommendation made on how to proceed with the New York Tappan Zee bridge project.

2.2 Scope

This report is aimed to provide a high-level overview of the proposal and analysis of the Tappan Zee bridge project. This includes a detailed analysis of the economic, environmental and social impacts of the project and its alternatives. This report will not cover details of the chosen bridge alternatives such as structural engineering analysis on the bridge materials or infrastructure.

2.3 Main Points

The main points in this document include:

- A brief introduction to the New York Tappan Zee project
- Motivation and objectives behind this project
- Economic, Environmental, and Social Analysis
- Conclusion and recommendations

2.4 Main Conclusions

The results of the economic, social impact and environmental impact analyses have produced substantial evidence in the deliberation of bridge construction options. The main economic conclusion was that the capital costs and maintenance costs of a replacement option were lower and had higher benefits compared to the rehabilitation option. Furthermore, the social impact analysis demonstrated that the replacement option is the preferred option due to improvements such as enhanced traffic safety. Moreover, the environmental analysis revealed that the replacement option would have a higher environmental impact initially. However, in the long term, the rehabilitation option would incur greater disruption due to more frequent large scale maintenance.

2.5 Main Recommendations

Both the rehabilitation and the replacement option have similar environmental impacts and social impacts. However, the Replacement option offers lower capital costs, maintenance costs, better structural safety, and a smaller long term environmental footprint. With the do-nothing option not viable due to public safety concerns, it is recommended that the New York state government proceed with the replacement option.

3 Introduction

3.1 Background

The Tappan Zee Bridge was constructed in 1995 and spans the Hudson River. It is the only crossing between the Westchester and Rockland counties. The loss or disruption of this critical crossing would compromise the economic vitality of the region. It is the longest bridge in New York with a total length of approximately 4.8km. The bridge is a 2,415 foot cantilevered truss design that accommodates seven lanes of traffic. It was initially designed to handle 100,000 vehicles per day but after its construction only saw a total of 18,000 vehicles daily. Eventually, by 2000 it carried over 135,000 vehicles per day. In the next two decades, the Tappan Zee Bridge is projected to carry 175,000 vehicles per day. The bridge was built with a construction budget of only $81 million and had a design life span of 50 years [1]. In the 2000s, the bridge was deemed to be decaying and overburdened with significant maintenance costs and traffic overcapacity. Concerns about the structural integrity of the Tappan Zee Bridge prompted an exploration of replacement or rehabilitation options for the bridge.

3.2 Motivation

There are several problems associated with the Tappan Zee Bridge. The most prominent issue is that the bridge has exceeded its designed life space of 50 years. Furthermore, bridge maintenance costs have risen dramatically due to the unusually high deterioration rate of the bridge, which is the result of a flawed design. A large number of joints and steel sections that were a part of the supporting structure are left vulnerable and exposed. These sections are constantly experiencing erosion from de-icing salt and the unique salt-water environment of the Hudson River. These damages have only been amplified by the large traffic throughput, which is 35% higher than the designed capacity. This issue of high traffic volumes compounded by the lack of road shoulders makes maintenance inaccessible without major hindrance to the transportation system in the surrounding area. Another problem is the abnormally high motor vehicle accident rates. This is due to the lack of essential safety infrastructures such as shoulders and emergency lanes, combined with poor design choices such as a narrow lane width and an inadequate drainage system. Finally, the Tappan Zee bridge offers no support for a public transit system to meet today's transportation demands. It is also worth mentioning that the New York State Thruway Authorities would not address any of the above concerns due to limited resources.

3.3 Objectives

All design alternatives discussed will strive to meet these objectives:

1) Improve the transportation of people, goods, and services across New York
    a) Reduce traffic congestion levels.
    b) Improve travel times for local and business trips.
    c) Provide a means of travel for non-motorized travel such as bicycle and pedestrian lanes.
    d) Provide alternative modes of travel not subject to roadway congestion.
2) Increase flexibility and adaptability of bridge infrastructure to accommodate changing future demands
    a) Ensure that all safety requirements are met and structural integrity is preserved for any future expansions and maintenance.
3) Uphold vital elements of transportation infrastructure
    a) Ensure that transportation infrastructure meets all standards for structural design and integrity.
4) Improve safety and security of those using the bridge
    a) Reducing motor vehicle accidents.
    b) Improve the roadway geometric design to meet current standards.
    c) Reduce the possibility of civilian and property damage in the case of severe natural or manmade events.
5) Minimize and avoid negative impacts caused by maintenance or improvements to the bridge
    a) Minimize and mitigate environmental impacts on the surrounding ecosystems.
    b) Minimize any disruption, displacement, and reallocation events that could affect the public.

3.4 Report Layout

In the following section, there will be an economic, environmental, and social analysis between the rehabilitation option versus the replacement option. After the analysis, the report will summarize the findings and recommend the best option that should be taken.

4 Body

There are 3 designs that are proposed. The first design is the base case where we do nothing, the second choice is to rehabilitate the existing bridge, and the third choice would be to replace the existing bridge.

However, the Do nothing option is not actually feasible and safe. This is because, from a government perspective, the bridge has already exceeded its lifespan and is experiencing an unusually high deterioration rate. It is not safe for the public and those using the bridge to do nothing. Additionally, the existing Tappan Zee Bridge was designed in accordance with the requirements listed in the 5th edition Standard Specifications for Highway Bridges created by the American Association of State Highway Official (AASHO) [13]. This design currently does not comply with roadway geometric design and traffic safety standards.

Therefore, there will be only 2 designs that we will be comparing and performing analysis on, the rehabilitation option and the replacement option.

Figure[3]: Rehabilitation Option - Existing structure will be strengthened & widened. Picture Source: [13]

Figure[4]: Replacement Option - Existing structure will be torn down & replaced. Picture Source: [13]

To keep things consistent, both the replacement option and the rehabilitation option will have the same features. They will both include [13]:

- 8 General purpose (GP) lanes
- 2 BRT/HOV lanes
- 2 Pedestrian and Cycle paths

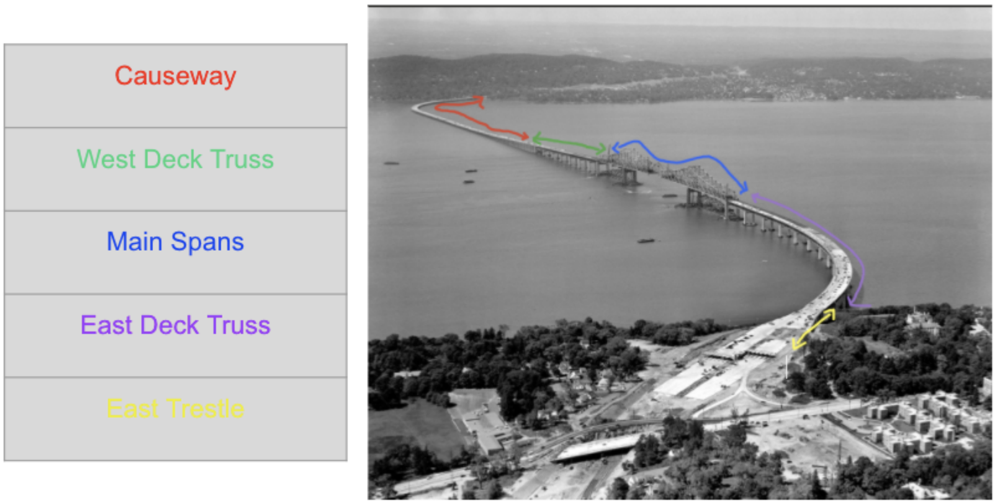
4.1 Methodology

This report will utilize several criteria to perform the economic, environmental and social impact analyses of the Tappan Zee Bridge. The economic analysis will consist of capital costs, maintenance costs and estimated benefits. Furthermore, the report will consider payback period, present worth method and cost-benefit analysis to compare the two bridge options. An environmental impact analysis will evaluate environmental risks such as shading of the river bottom and impacts to water quality. It will take into account long term and short-term effects of construction. Lastly, a social impact analysis will examine travel time, traffic safety, noise level, urban sprawl and land acquisitions.

4.2 Economic Analysis

The economic analysis involves examining the different costs and benefits associated with the rehabilitation and replacement option for the project. Methodologies such as payback period, net present worth method, and cost/benefit analysis will be used to determine the economic viability of both projects, and to choose one alternative over the other.

4.2.1 Bridge Structure Breakdown



Figure[5]: Economic Analysis Breakdown [1]

To start the economic analysis, a breakdown is created of the bridge components. There is the causeway, west deck truss, main spans, east deck truss, and east trestle as our bridge components. This breakdown can be used to estimate costs for the 2 alternatives based on these different components and the work needed for those parts of the bridge. This breakdown provides a good level of granularity to begin the economic analysis for the bridge.

4.2.2 Capital Costs

Bridge Component	Rehabilitation Option (2012 millions)	Replacement Option (2012 millions)
Causeway	60	60
West Deck Truss Spans	720	20
Main Spans	1910	20
East Deck Truss Spans	1060	30
East Trestle	70	5
West Approach	2420	2830

Main Span	-	1170
East Approach	-	970
Non-structural	150	150
Total	6390	5255

Table[1]: Capital Costs Breakdown

The total capital costs of each alternative at present worth (starting in 2012) were calculated. The cost of the bridge components was itemized and then tallied up in the table shown. The rehabilitation option is approximately 6.4 billion dollars and the replacement option is approximately 5.3 billion dollars [2]. One can see that the rehabilitation option is around 1 billion dollars more compared to the replacement option. This is due to the substantially higher costs associated with construction to and around the existing bridge. Costs would be higher considering the complexities of widening the existing structure and the difficulty of working around existing traffic. This may also cause the rehabilitation option to progress at a slower rate compared to the replacement option and potentially incur higher insurance costs.

4.2.3 Maintenance Costs

Bridge Component	Rehabilitation Option (2012 millions)	Replacement Option (2012 millions)
Causeway	-	-
West Deck Truss Spans	200	-
Main Spans	500	-
East Deck Truss Spans	300	-
East Trestle	80	-
West Approach	160	260
Main Span	-	100
East Approach	-	120
Non-structural	70	200
Staffing	200	100

Total	1510	780

Table[2]: Maintenance Costs Breakdown

Furthermore, the maintenance costs were calculated using the net present worth method. This was used to evaluate the amount of money needed to set aside in 2012 to cover future maintenance costs for 150 years assuming a discount rate of 3% [2]. Future maintenance costs were also evaluated depending on the age of components and their respective locations. For example, using new concrete may be constructed to a higher standard than existing components leading to a longer period between repairs, therefore reducing maintenance costs.

Here is a sample calculation of the present worth maintenance costs [3]. The estimated annual maintenance cost of the main span component for the bridge was about 15.18 million dollars.

$$(P/A, 3\%, 150) = \frac{(1+i)^N - 1}{i(1+i)^N} = \frac{(1.03)^{150} - 1}{0.03(1.03)^{150}} \approx 32.94$$

$$P = A * (P/A, 3\%, 150) \approx 15.2 million * 32.94 \approx 500\, million$$

After all the calculations. We can see that the replacement option has a lower total present worth maintenance cost of 780 million compared to the rehabilitation option which was 1510 million.

4.2.4 Benefits

Benefits	**Rehabilitation Option (millions)**	**Replacement Option (millions)**
Net Toll Revenue	642	825
Special Permit	13	13
Cost savings commercial traffic	40	40
Cost savings from reduced operational cost	-	22
Recreational benefits	20	20

(supporting parks, travel)		
Total	715	920

Table[3]: Benefits Breakdown

These are the benefits of the project estimated at an annual worth. The total for rehabilitation is 715 million dollars, and for replacement is 920 million dollars. The replacement option has a higher benefit from reduced maintenance costs and higher tollway revenue.

The benefits consist of things such as net tollway revenue, permit fees, cost savings for commercial traffic, cost savings from reduced operational cost, and from recreational benefits. These benefits were inspired by a 2012 financial statement provided by the new york state thruway authorities [4].

4.2.5 Payback Period

	Rehabilitation Option (2012 millions)	**Replacement Option (2012 millions)**
First Costs	$6390	$5255
Annual Profits	$187 [5]	$370 [5]
Payback Period	34 years	**14 years**

Table[4]: Payback Period Analysis

The majority of this project will be financed using government entities. This will consist of federal loans and issued bonds such as the Transport Infrastructure Finance and Innovation Act (TIFIA) loan [6]. These loans will be paid back primarily via toll collection and other ancillary fees such as special permits.

Thus, we can first examine the payback period for both alternatives. Below is a sample calculation [3]:

$$Payback\ Period = \frac{First\ Cost}{Annual\ Profits} = \frac{6390}{187} = 34\ years$$

The calculated payback period of the rehabilitation option is based on an annual profit of $187 million dollars that accounts for operating costs and revenues based on existing toll revenue. The payback period of the rehabilitation option is 34 years.

The calculated payback period of the replacement option is based on an estimated annual profit of $370 million dollars. The higher annual profit is due to an expected improvement in traffic throughput and higher tolls. The payback period of the replacement option is 14 years, which is much lower than the rehabilitation option.

4.2.6 Cost-Benefit Analysis

Modified B/C	**Replacement**	**Rehabilitation**
Benefit (millions)	(30304.8 - 780) = 29524.8	(23552.1 - 1510) = 22042.1
Cost (milions)	5255	6390
Modified B/C	5.62	3.45

Table[5]: Cost-Benefit Analysis

The cost-benefit ratio is seen below [3]:

$$B/C = \frac{Benefits - Disbenefits - O\&M\ Costs}{Cost} = \frac{B-D-OM}{C}$$

Note that the numerator consists of Benefits - Maintenance cost.

For the Benefits - Cost (otherwise known as PW) method [3], we showed the calculation below. We can first convert our estimated benefits to preset worth.

<u>Replacement Option</u>:

$$(P/A, 3\%, 150) = \frac{(1+i)^N - 1}{i(1+i)^N} = \frac{(1.03)^{150} - 1}{0.03(1.03)^{150}} \approx 32.94$$

$$P(present\ worth\ benefits) = A * (P/A, 3\%, 150) \approx 920\ million * 32.94 \approx 30304.8\ million$$

$$B - C = 30304.8\ million - 5255\ million = +\ 25049.5\ million$$

<u>Rehabilitation Option</u>:

$$P(present\ worth\ benefits) = A * (P/A, 3\%, 150) \approx 715\ million * 32.94 \approx 23552.1\ million$$

$$B - C = 23552.1\ million - 6390\ million = +\ 17162.1\ million$$

The modified cost-benefit analysis was used to analyze the 2 alternatives. After conducting this analysis, the replacement option had a higher benefit and lower cost when compared to the rehabilitation option. This supports choosing the replacement option. In order to support this result, a net of benefit-cost method at present worth was also conducted. The result of this analysis also showed that the replacement option had a higher present worth (+25049.5 million) over the rehabilitation option (+17162.1 million) which again supports choosing the replacement option.

4.3 Environmental Impact Analysis

4.3.1 Overview

The Tappan Zee bridge is located at the estuary of Hudson River, which supports a rich diversity of aquatic life including fish, crabs, shellfish and invertebrates. The river provides habitats that support the spawning and nursery of many marine species both found in the shallows and in the deeps. These habitats provide significant value to both land and aquatic wildlife in the regional ecosystem and are homes to many important fauna in this part of the river [7].

Due to its high ecological importance, the project site is part of the US Fish and Wildlife Service designated Significant Habitats of the New York Bight Watershed. It is managed by a variety of laws including the Clean Water Act, Endangered Species Act, Rivers and Harbors Law, and many more [7].

4.3.2 Environmental Assessment Criteria

This section analyzes the environmental impact of the project on the Hudson River estuary. The analysis develops several criteria for environmental assessment based on the disruptive impacts of the construction process itself, as well as future, long-term impacts of the new structures. These criteria include short-term construction impacts, long-term construction impacts, shading of river bottom, sediment resuspension, and water quality impacts.

Short-term construction impact refers to the temporary disruptions to the river's ecosystem during the construction process. This may include acoustic impact generated by the construction machines, the contaminants released into the water, and other impacts that disrupt and kill wildlife living in the estuary [7]. Avoiding fish spawning season and using bubble curtains are ways that these disruptions can be mitigated, but it is also possible to limit the construction scale to keep the impacts under control [8].

The main long-term construction impact is the direct invasive impact of installing piers. The process will likely kill plants and animals living on the river bed, resulting in permanent loss of habitats [7]. Unfortunately, there is no effective way to mitigate this impact. The analysis evaluates this impact by the acres of riverbed affected by the process.

A secondary long-term impact is the bridge shading over the river surface. This can kill algae, disrupting the ecosystem that depends on them [7]. There is no effective way to mitigate it. The analysis evaluates this impact based on the area of the bridge deck. Please note that while the height of the bridge and the angle of the sun also plays a role in the shading area, their effects on the estimation are not significant.

The construction process will also cause sediment resuspension. This can suffocate wildlife living on the river bottom. Moreover, sediment resuspension releases contaminants from the sediment that accumulates in fish tissues [7]. It is possible to mitigate this impact by limiting the scale of construction to one portion of the river at a time to avoid large-scale effects or using silt curtains and cofferdams. The main cause for sediment resuspension installing cofferdams. Hence, the analysis estimates the impact by calculating the number of cofferdams required.

Finally, the stormwater runoff from the bridge could wash toxic substances such as de-icing salt and chemicals from the asphalt into the river, reducing water quality and disturbing aquatic wildlife both at the estuary and downstream [7]. It is possible to reduce the impact by using environment-friendly methods for de-icing and pavement, etc. This impact is evaluated based on the surface area of the bridge deck since the amount of pollution is directly proportional to that.

A summary of the assessment criteria can be found in the table below.

Assessment Criteria	Environmental Impact	Risks	Mitigation
Overall Short term impact	Temporary disruption to habitat due to construction process	Killing and disrupting wildlife [6]	Limit the construction scale, avoid construction during peak fish spawning season, use bubble curtains to reduce acoustic effects [7]
Overall long term structure impact	Installment of piers disrupts river bed	Loss of river bed habitats	No effective mitigation method
Sediment Resuspension	Construction causes sediment resuspension	Releasing contaminants & suffocating wildlife on the river bottom [7]	Limiting the construction scale to one portion of the river at a time and/or using silt curtains and cofferdams to limit the sediment released into the environment [7]
Shading over river surface	Bridge shading over the river surface	Killing algae and disrupting the ecosystem [6]	No effective mitigation method
Water Quality	Bridge stormwater runoff polluting the river water quality	Disturbs aquatic wildlife at the estuary and downstream. [6]	Use environmentally friendly material for bridge maintenance and de-icing.

Table[6]: Environmental Analysis Assessment Criteria Summary

4.3.3 Options Comparison

Short-term construction impact is estimated based on the maximum number of acres of river bottom that will be affected during construction. A larger affected area would imply a greater impact on the ecosystem. It is estimated that both the rehabilitation and the replacement option would affect similar acres of the river bottom. This is because regardless of the scale of the project, the construction will be carried out in multiple portions. The maximum area of effect during each portion of the construction will be similar across both options.

Long-term construction impacts refer to the acres of river bottom that will be affected due to the construction of piers. Due to the slightly bigger size of the replacement structure, the replacement option has a slightly higher long-term construction impact compared to the rehabilitation option.

The criterion shading of the river bottom is evaluated based on the size of the bridge deck. Again, due to the larger size of the structure, the replacement option has a slightly larger 61 acres of shading compared to the rehabilitation option's 56 acres of shading.

The resuspension of sediments in the river bed is due to the process of construction sheet pile cofferdams. According to the estimations, the rehabilitation option would require 60 cofferdams to be installed while the replacement option would require 70. Hence, the rehabilitation process would have a smaller impact on resuspending sediment.

Stormwater runoff from the bridge negatively affects the water quality. This effect is directly proportional to the surface area of the bridge deck The replacement option has a larger bridge deck area of 77 acres compared to the rehabilitation option's 63 acres. This suggests that the replacement option would have a more significant impact on the water quality of the Hudson River.

A summary of the options comparison data is found in the table below.

Assessment Criteria	Rehabilitation Option	Replacement Option
Short Term construction impact (Acres)	4	4
Invasive long term construction impact (Acres)	10	11
Shading of river bottom (Acres)	56	61
Sediment resuspension (number of cofferdams)	60	70
Water quality Impact (Deck area)	63	77

Table[7]: Environmental Analysis Options Comparison

4.4 Social Impact Analysis

As a bridge that connects millions of people to/from New York City, the decision to rehabilitate the bridge or replace it has the potential to impact millions of lives. Therefore, it is important to ensure that the social impact of every option is taken into consideration. The social impact section below is broken into multiple subheadings, each of them addressing different social impacts.

4.4.1 Travel Time

One of the goals of this project is to improve mobility in the corridor and to ensure that the mobility capacity is sustainable for the present and the future. In this project, mobility is measured in terms of Transit Ridership, Road Congestion, and Transit Capacity. Since both rehabilitation and replacement options have the same number of general-purpose lanes, BRT/HOV lanes, and pedestrian/bicycle paths, either option achieves the same reduction in travel time (expected travel time decreases by an average of 18.77 minutes across 22 trip pairs [9]). The do-nothing option is therefore only there as a benchmark for improvement.

	Do Nothing Option	**Replacement/Rehabilitation Option**
Transit Ridership	161,400	184,800
Road Congestion	139,600	135,300
Transit Capacity	N/A	2,000

Table[8]: Social Impact of Different Options. Source of data: [9]

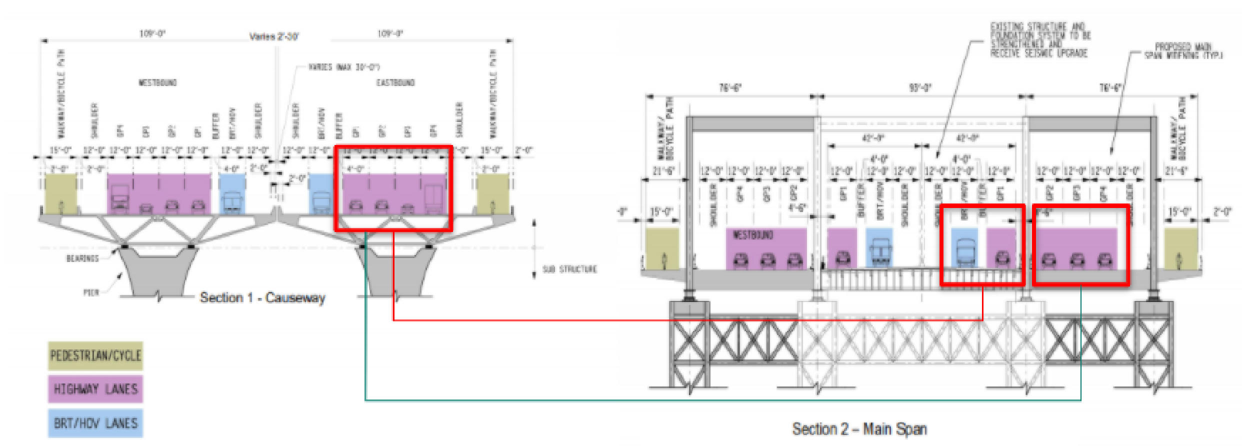
The definitions are as follows:

- Transit ridership means the total number of daily transit trips. The increase in transit ridership observed by both replacement and rehabilitation options are a result of the added transit options.
- Road Congestion is measured by the number of vehicles crossing the bridge during the morning peak period. It should be noted that the number of vehicles decreased by 4300 for the replacement/rehabilitation option because they are diverted through the newly added transit options.

- Transit Capacity represents the public transit ridership capacity during peak hours. The observed increase is due to the same aforementioned reasons.

4.4.2 Traffic Safety

The rehabilitation option would improve the roadway geometry by including continuous 12-foot lanes without transition curves and utilize outside and median shoulders [10].



Figure[6]: Rehabilitation Design Safety Analysis

Upon analyzing this design, there are two potentially unsafe conditions that arise. The first unsafe condition comes from the transition from section 1 to section 2 of the bridge. Both eastbound and westbound lane groups split to avoid the main span trusses. This is shown in the red and green boxes in Figure [6]. A deep look into the design reveals that in section 2 one GP lane is paired with the BRT/HOV lane (main span) while the remaining three GP lanes will be outside of the main truss section [9]. This is a major problem as those unfamiliar with this split would intuitively slow down or make sudden lane changes which could lead to an increase in motor vehicle accidents.

The second unsafe condition is related to the end of the split in the eastbound direction where the lanes are rejoined. After the split, motorists would need to position themselves in the correct lanes as they approach either the E-Z Pass lanes, Toll Booths, or the Interchange 9 exit [9]. Given that there are 4 GP lanes, cars will be weaving in both directions to get to the correct lane while traversing the long curve that terminates into the plaza. This will cause turbulence in the traffic flow and will greatly increase the number of motor vehicle accidents. In addition, the available weaving distance from the end of the split to the start of the plaza is less than the recommended length to weave across four highway lanes. The recommended distance is 3,000 ft to move from the far left lane to the outer right lane. However, only approximately 2,500 ft is available [9].

Similar to the rehabilitation option, the replacement option will provide similar traffic safety features. However, the main difference is that the replacement option will provide lane continuity across the bridge and there will be no split. The roadway cross-sections would also be designed with respect to the current applicable standards outlined in the 7th edition Standard Specifications for Highway Bridges created by AASHO [9]. Since the current safety standards will be incorporated in the replacement option, there would be no related traffic safety issues.

Overall, the rehabilitation option introduces a lane split in the middle of the bridge. This is an undesirable highway feature that will compromise traffic safety and cause confusion to new drivers of the bridge. This lane separation would create a permanent safety deficiency.

In terms of traffic safety, a comparison between the rehabilitation option and replacement option favours the replacement option much more as it follows current safety standards and roadway geometric design.

4.4.3 Noise Level

In 2010, the New York State Thruway Authority (NYSTA) and the New York State Department of Transportation (NYSDOT) published a report to analyze the traffic noise levels. In particular, the report focused on these major areas in their analysis [12]:

1) Volume of Traffic
2) Speed of Traffic
3) Number of trucks in flow of traffic
4) Distance from the Traffic

When comparing the rehabilitation option against the replacement option, the report concluded that there was no substantial difference between the two alternatives [12]. For each option, the predicted traffic noise levels would not be substantially different from the existing noise levels coming from the Tappan Zee bridge.

4.4.4 Urban Sprawl

The New York Metropolitan Transportation Council (NYMTC) published a report in 2010 that outlines the expected rate of growth from 2010-2017 [11], which was estimated based on the current Tappan Zee bridge. It is evident that both counties have a small increase in growth. From 2010-2047, we can see a similar pace of growth.

Table 8-2
NYMTC Population Projections (in 000s)

	2010	2017[1]	2020	2030	2040	2047[1]	2010-2017 Percent Change	2010-2047 Percent Change
Rockland County	311.7	320.5	324.3	339.3	363.6	375.7	2.8%	20.5%
Westchester County	949.1	978.0	990.4	1,055.1	1,133.7	1,176.8	3.0%	24.0%

Note: [1] 2017 and 2047 population projections were based on extrapolation of NYMTC data.
Source: New York Metropolitan Transportation Council, July 2011

Figure[7]: Population Projections From Existing Tappan Zee Bridge. Source of data: [11]

From Figure [7], the effect of the existing bridge has on urbanization on both counties is quite apparent. The bridge connects Rockland and Westchester counties and was one of the main factors behind the urbanization of the Rockland county. In fact, five years after the bridge opened in 1955, the population of Rockland county increased by 50 percent [9]. This bridge is crucial in connecting both counties over the Hudson River.

In reality, the Tappan Zee bridge is not just a bridge. They are wonderful marvels of engineering that have a social, commercial, political, and economic impact on society. Whether the decision is to rehabilitate the bridge or replace it, any improvements to the bridge has a direct impact on society. The improvements to the bridge will expedite urbanization, increase tourism, expand businesses, and widen employment and real estate opportunities.

4.4.5 Land Acquisition

	Rehabilitation	**Replacement**
Rockland County	Acquisition of a part of Elizabeth Place Park	Acquisition of a part of Elizabeth Place Park Acquisition of one residential property (1 River Road)
Westchester County	Acquisition of a 20 ft x 560 ft property from “The Quay Condominium”	Acquisition of a 20 ft x 560 ft property from “The Quay Condominium”

Table[9]: Land Acquisition for Both Options. Source of Data: [11]

<u>Rockland County</u>

In the above Table [9], both the rehabilitation option and the replacement option need to acquire a part of the Elizabeth Place Park and the access way to the park [11]. This is to help with the widening of the highway and the reconfiguration of Interchange 10. There will also be displacement of one residence at the corner of Elizabeth Place and South Broadway (306 South Broadway) because of the construction of the Broadway Bridge over the Thruway. It is worth mentioning that the replacement option would require an additional acquisition of a residential property (1 River Road) [11].

<u>Westchester County</u>

Both the rehabilitation option and the replacement option would need to acquire a strip of property (approximately 20 feet x 560 feet) from The Quay Condominium [11]. The acquisition of The Quay property would lead to a displacement of one tennis court used by residents.

5 Conclusions

Economic Analysis:

The results of the economic analysis demonstrate several key findings. The rehabilitation option offers higher capital costs compared to the replacement option due to higher costs associated with work conducted on and surrounding the existing structure. The maintenance costs of the rehabilitation option are higher as well compared to the replacement option due to the older age of components. The predicted benefits of the replacement option compared to the rehabilitation option were higher as well. The calculated payback period was lower for the replacement option at 14 years compared to 34 years for the rehabilitation option. Finally, the cost-benefit analysis revealed that the replacement option had higher benefits and lower costs compared to the rehabilitation option.

Environmental Impact Analysis:

According to the environmental analysis, it was observed that the alternatives yield similar environmental impacts. Both options also have the same mitigation techniques in order to limit these impacts. However, it was demonstrated that the replacement option had slightly larger environmental impacts in some areas such as sediment resuspension and impacts on water quality. This was a result of its generally larger structure in comparison to the rehabilitation option. Although this is the case, the differences are not significant. Therefore, it was concluded that both options are viable from an environmental impact standpoint.

Social Impact Analysis:

From the various social analysis performed above, either option will have similar social impacts in terms of travel time, noise level, and urban sprawl. Similarly, the amount of land needing to be acquired between both options are comparable, with the replacement option needing to acquire one more small property in Rockland county. However, there is a significant difference in terms of traffic safety for both options. As discussed in section 4.4.2 above, the replacement option complies with current safety standards, and follows modern roadway geometric design. The rehabilitation option, on the other hand, introduces a lane split in the middle of the bridge. This is an undesirable highway feature that will compromise traffic safety and cause confusion to new drivers of the bridge.

6 Recommendations

From the conclusion, the recommended alternative is the **replacement option**. Both the rehabilitation and the replacement option have similar environmental impacts and social impacts. However, the replacement option offers lower capital costs, maintenance costs, better structural safety, and smaller long term environmental footprints. In terms of traffic safety, the replacement option also conforms with current safety standards and roadway geometric design. The do-nothing option as mentioned in the beginning is not viable due to public safety concerns. Therefore, it is recommended that the New York state government proceed with the replacement option.

It is worth mentioning that there are several considerations or procedures in the studied project that should be examined for future recommendations and analysis.

For the economic analysis, calculations were based on estimated numbers for predicted bridge costs and projected maintenance costs. These were collected with the current construction estimates and current data on the bridge. In the future, these predictions could be improved with greater granularity. For example, including possible insurance costs or ancillary costs is recommended for analysis. It is also recommended that future state governments consider a separate study on toll revenue to gather data on its ability to raise funding to cover its loans for bridge construction.

For the environmental analysis, the data used for evaluating the environmental impact and for the options comparison are based on rough estimates of the area of the bridge. Many factors are ignored in the estimation process. It is recommended that future studies should conduct engineering surveys to obtain accurate data and have professional analysts calculate the environmental impact to obtain accurate results.

In the future, other social impacts such as cultural impact and the number of new employment opportunities created from the bridge should be taken into consideration. Additionally, one big factor that was not mentioned was the timeline of the project. Both the rehabilitation and replacement options would have different timelines. A future study should compare the timeline of the projects in the social impact analysis.

7 References

[1] “In Tappan Zee, Replacement, Location Adds to the Cost”, Dec. 17, 2012. [Online]. Available: https://cityroom.blogs.nytimes.com/2012/12/17/years-after-its-expiration-date-a-plan-to-rebuild-the-tappan-zee-bridge/

[2] “Executive Summary.” [Online]. Available: https://www.newnybridge.com/documents/study-documents/old-study-docs/alt-analysis/rnr-executive-summary-200903.pdf [Accessed: 28-Mar-2021].

[3] M.M.A Salama, “ECE 390 Winter 2021 Lectures 9-12”, Department of Electrical and Computer Engineering, University of Waterloo, Waterloo [Accessed: 28-Mar-2021].

[4] “Monthly Financial Report December 2012.” [Online]. Available: https://www.thruway.ny.gov/about/financial/monthly/2012/supplementals/dec2012supplements.pdf [Accessed: 28-Mar-2021].

[5] New York Thruway Authority, “Monthly Financial Report December 2018,” thruway.ny.gov, Dec-2018. [Online]. Available: https://www.thruway.ny.gov/about/financial/monthly/2018/supplementals/dec2018supplements.pdf. [Accessed: 28-Mar-2021].

[6] P. O. and J. Dague, “Bridging the financial gap,” 13-Oct-2017. [Online]. Available: https://cbcny.org/research/bridging-financial-gap. [Accessed: 29-Mar-2021].

[7] “Environmental Criteria,” Alternatives Analysis for Rehabilitation and Replacement of the Tappan Zee Bridge. [Online]. Available: https://www.newnybridge.com/documents/study-documents/old-study-docs/alt-analysis/rnr-chapter-6-200903.pdf.

[8]“Governor Cuomo Releases final environmental impact statement for new bridge to replace the Tappan Zee.” [Online]. Available: https://www.governor.ny.gov/news/governor-cuomo-releases-final-environmental-impact-statement-new-bridge-replace-tappan-zee. [Accessed: 28-Mar-2021]

[9] “Transportation Criteria,” Alternatives Analysis for Rehabilitation and Replacement of the Tappan Zee Bridge. [Online]. Available: https://www.newnybridge.com/documents/study-documents/old-study-docs/alt-analy

sis/rnr-chapter-7-200903.pdf.

[10] “Tappan Zee Bridge Rehabilitation Options,” Alternatives Analysis for Rehabilitation and Replacement of the Tappan Zee Bridge. [Online]. Available: https://www.newnybridge.com/documents/study-documents/old-study-docs/alt-analysis/rnr-chapter-3-200903.pdf.

[11] “Socioeconomic Conditions,” Tappan Zee Hudson River Crossing Project Environmental Impact Statement. [Online]. Available: https://www.newnybridge.com/documents/feis/vol1/08-socioeconomic-conditions.pdf.

[12] “Noise and Vibration ,” Tappan Zee Hudson River Crossing Project Environmental Impact Statement. [Online]. Available: https://www.newnybridge.com/documents/feis/vol1/12-noise-and-vibration.pdf.

[13] “Engineering Elements,” Alternatives Analysis for Rehabilitation and Replacement of the Tappan Zee Bridge. [Online]. Available: https://www.newnybridge.com/documents/study-documents/old-study-docs/alt-analysis/rnr-chapter-2-200903.pdf.