BRIDGE LIFETIME EXPENSE STUDY USING ASSET VALUATION AND CONJOINT ANALYSIS TECHNIQUES TO ASSIST IN DECISION MAKING FOR LONG-TERM TRANSPORTATION ASSET MANAGEMENT PLANS

by

ADARA DODSON

(Under the Direction of Mi Geum Chorzepa)

ABSTRACT

The objective of this thesis is to develop an asset valuation approach that will assist Georgia Department of Transportation (GDOT) engineers in making decisions on bridge maintenance. The approach will utilize resources acquired from the element-based bridge inspection database from GDOT and recorded maintenance from the National Bridge Inventory (NBI), while improving upon current techniques such as the bridge health index. The asset valuation technique will then be used as a tool in determining bridge preservation activities such as maintenance, repair, or replacement. Asset valuation will be achieved through the use of weighting factors developed from a conjoint analysis, application of maintenance data through a cash flow analysis, and an element unit cost database. The cash flow analysis and collection of element unit costs used GDOT maintenance and NBI data to log the changing costs of bridge elements and maintenance budgets. The conjoint analysis was designed to determine factors that most affect the bridge's health. Results from the study show trends in element costs over the years, use maintenance expenses over a bridge's lifetime to determine future rehabilitation actions, and correct health index values to better represent bridge health.

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1. INTRODUCTION

1.1 Background

Asset valuation is the assignment of a monetary value to infrastructure based upon its size, age, replacement cost, and original cost to construct (“FHWA”, 2016). The process of allocating a monetary value to infrastructure is beneficial, as it places importance on maintaining a structure’s worth. Proper maintenance ensures bridge health, as well as the public’s equity.

Element based inspections are still a new form of inspection that have great potential if thoroughly studied. Therefore, the use of the inspection type was incorporated into the research study. Element-based bridge inspection is considered more comprehensive than previous methods, such as NBI general condition inspections. Element-based inspections rate each individual bridge element rather than grading the bridge as a whole, proving to be more thorough. There are a total of over 500 individual elements belonging to more generalized groups such as decks/slabs, or girders. Ratings range from one to four, where one indicates bridges in good condition, usually only requiring preservation/cyclic maintenance. Four is severe condition, often calling for action of either rehabilitation or replacement.

A bridge’s health index is a numbered valuation of its condition based upon factors observed during bridge inspections. The health index assists engineers in determining the structures overall condition, as well as helps when making decisions about maintenance or replacement. The bridge health index was first proposed for use on California bridges to represent the overall physical condition of a bridge (Inkoom et al., 2017). The Georgia Department of Transportation (GDOT) adopted the health index along with National Bridge Inventory (NBI) inspections to manage a bridge’s health. However, there is concern that the health index does not take into account environmental and indirect factors that will not be able to be represented in inspections and consequently in the health index. Therefore, the health index is in need of modifications.

The Virginia Department of Transportation (VDOT) has been nationally leading the asset valuation effort using the health index and sharing the knowledge through TRB/ASCE webinars and is currently seeking three bridge and/or tunnel asset management engineers for its Bridge Maintenance Program. VDOT manages the vast majority of the statewide inventory of over 21,000 bridges and culverts with the following four goals: “maximize service life, minimize life cycle costs, minimize risk, determine predictive indicators of performance, and determine the most effective maintenance and construction practices”. VDOT has bridge assets valued in excess of $50B with annual maintenance and construction programs budgeted in excess of $400M. Therefore, it believes that “maintenance practices need to be especially strategic given that the average age of a bridge is 50 years old”, and the bridges have service life of approximately 50-years. It also believes that “the Bridge Management Engineer positions will require solid education, work experience and/or skills in data-driven analysis to assist with our intensive bridge management system analysis” (VDOT, 2019).

With the positive changes in the practice of bridge asset management, this study aims to develop an asset valuation approach that will utilize resources acquired from the element-based bridge inspection database from GDOT, while improving upon current techniques such as the health index. The asset valuation technique will then be used as a tool in determining bridge preservation activities such as repair or replacement.

This study will be able to demonstrate the importance of bridge asset valuation through extended service life. The results have the potential to have an impact on how GDOT allots money to deteriorating bridges. Bridge engineers often mentioned that past asset management plans have misrepresented the current state of bridges, causing for large sums of money to be repeatedly put into bridge maintenance or repair that does not optimize the budget. The current study has the ability to assist in accurately weighing economical decisions, and aims to aide in decision making that is best for the budget and the lifespan of any bridge selected.

1.2 Literature Review

1.2.1 *Review of U.S. Bridge Management Practices*

Bridge performance levels are regularly assessed to provide accurate knowledge of their health. Each state's Department of Transportation has their own methods to determine performance and health. The California Department of Transportation (Caltrans) uses a bridge element inspection manual similar to the AASHTO manual for bridge element inspection. Caltrans also uses specialized equipment such as ground penetrating radar for data collection along with AASHTOWare bridge management software. The department performs routine, preventative rehabilitation, and emergency maintenance. The effectiveness of its bridge management program is determined by analyzing the number of bridges that transition from maintenance to rehabilitation and replacement (Caltrans, 2018).

Virginia department of transportation (VDOT) uses a supplement to the AASHTO manual. Similar to Caltrans, VDOT uses AASHTOWare software for bridge management. However, VDOT performs preventative, restorative, rehabilitation, replacement, inspection, and engineering in terms of maintenance. To track the effectiveness of the bridge program, VDOT recognized primary and secondary bridge performance measures including ideal targets for bridges labeled structurally deficient (VDOT, 2018).

While Georgia has, in the past, used the National Bridge Inventory (NBI) general condition rating system, it is now moving toward the use of the more progressive element-based inspection method. The NBI method rates the three primary bridge components (deck, superstructure, and substructure) on a scale of one to nine with nine being excellent condition and zero being failed condition. NBI assess major components but does not accurately portray the whole bridge condition. The ratings may also introduce biases. For example, bridge inspectors often have to identify the most severe cause of distress (Dojutrek et al., 2012). On the other hand, element-based condition states rate each individual bridge element on a scale of one to four. With four being severe condition and one being good. It gives the bridge a single aggregated score based on the results of each individual element score. This method is considered to be more comprehensive and thorough in comparison to the previous NBI inspection method.

1.2.1.1 Transportation Asset Management Plans

Department of Transportations (DOTs) are required to set up transportation management plans (TAMP) ("U.S. Department of Transportation FHWA," 2017) to gather information about assets, their management strategies, long-term expenditure forecasts, and business management processes ("U.S. Department of Transportation FHWA," 2017). These plans are altered over the years to be used by Department of Transportations to attain a cost effective use of resources and justify spending. TAMP's are a unifying tool that are able to connect DOTs and stakeholders to businesses involved in the process, and allows all parties to be on the same page and informed on the whereabouts of infrastructure. The National Highway System (NHS) requires every state to develop a risk based asset management plan for NHS assets. Move Ahead Project for Progress in the 21st Century Act (MAP 21) defines asset management as a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information. To identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost (“U.S. Department of Transportation FHWA,” 2017). Bridges and pavements are required to be monitored, while infrastructure assets within the highway right away are only encouraged to be kept track of. Each state DOT asset management plan is required to have the following:

- A summary listing of the pavement and bridge assets on the National Highway System in the State, including a description of the condition of those assets
- Asset management objectives and measures
- Performance gap identification
- Lifecycle cost and risk management analysis
- Financial plan
- Investment strategies

Georgia Department of Transportation (GDOT) has created its own transportation asset management plan that uses data and engineering judgment to make suitable decisions for state infrastructure. Traditionally, Georgia has worked on structures in a “worst first” method. The “worst first” method fixes infrastructure ahead of an actual need, causing less money to be allotted to lower cost preventative maintenance activities (GDOT, 2018). However, in its latest transportation asset management plan, GDOT has stated it is determined to work on “most at risk” first infrastructure instead (GDOT, 2018). The objective is to be able to track, and make, progress on their performance activities that enhances asset management practices. Table 1 shows how the department plans to measure the performance of the structures. Asset management will be tracked by level of service which is determined by three factors:

- Strategic objectives – targeted condition levels that are closely tied to the Department's strategic goals
- Department-wide performance measures – quantifiable indicators of how the Department is meeting its objectives
- Customer feedback – Regularly administered employee, motorist and/or public opinion polls to evaluate the services provided

Table 1 - Bridge Level of Service Measures (GDOT, 2018)

Asset	Performance Measure	Description	Target
Bridge Structures	Percent of NHS Bridges in Poor condition as a percentage of total NHS bridge deck area	Bridge Conditions are based on the results of inspections on all Bridge structures. Bridges rated as "Poor" are safe to drive on; however, they are nearing a point where it is necessary to either replace the bridge or extend its service life through substantial rehabilitation investments.	< 10% (NHS) in Poor Condition
Bridge Structures	Percent of NHS Bridges in Good condition as a percentage of total NHS bridge deck area	Bridges rated as "Good" will be evaluated as to cost of to maintain Good condition. Bridges rated as "Fair" will be evaluated as to cost of replacement vs. rehabilitation to bring the structure back to a condition rating of Good.	≥ 60% (NHS) in Good Condition

GDOT initially starts with cost-effective preservation treatments by the life expectancy determined from past trends. GAMS is a software program used to analyze treatment strategies and the benefit cost ratio of pavement networks. Bridges are assumed to have a 75-year lifespan with a life cycle analysis taking consideration of: degradation curves, preventative maintenance items, and major rehabilitation items (GDOT, 2018). Cost-effective bridge projects are of priority and more likely to be worked on sooner and faster. GDOT takes into account risk and attempts to preserve infrastructure that is most at risk first. The process also works with National Weather Service, Georgia emergency management agency, Georgia State patrol, and other state and federal partners to be aware of natural disasters that may have impact on state infrastructure, as well as monitors high-risk assets.

The California transportation asset management plan intends to use asset condition data to reach transportation goals established in partnership with its contributing members. As displayed in Figure 1 stakeholders all have responsibilities to maintain the health of the state's infrastructure.

FHWA
- Establish national standards for performance measures for bridges and pavement.
- Adopt targets and performance measures reflecting state transportation goals and objectives.
- Review for completeness and process certification
- Monitor progress of the State towards achieving two and four year performance targets.

Caltrans
- Prepare a robust TAMP to guide transportation investments through the State Highway Operation and Protection Program (SHOPP) to achieve performance targets.
- Ensure the TAMP is consistent with applicable state and federal requirements.
- Establish 10-year performance targets to support long-range investment strategies.
- Develop two and four-year performance targets.
- Plan, design, and oversee construction of projects.

Commission
- Approve State Highway System (SHS) assets for inclusion in the Transportation Asset Management Plan (TAMP).
- Adopt targets and performance measures.
- Review and approve the TAMP.
- Report progress to the state legislature on Caltrans' progress towards meeting SHS performance targets.
- Review and adopt the SHOPP, consistent with the TAMP.

MPOs/RTPAs/Local Agencies
- Establish 4-year performance targets, or adopt the state DOT's performance targets.
- Develop long-range transportation plans reflective of TAMP goals.
- Plan, design, and oversee construction of local projects.

Figure 1 - Stakeholder Roles and Responsibilities (Caltrans, 2018).

California's transportation asset-management plan follows Federal Highway Association (FHWA) and National Bridge Inventory (NBI) standards while inspecting all state bridges.

Bridges are rated on an NBI scale from zero to nine, and overall ratings are given to the deck superstructure and substructure. The NBI scale is shown in Figure 2. Culverts longer than 20 feet are also included in this category and are rated in the same manner.

NBI Ratings	
9	
8	**Good**
7	
6	
5	**Fair**
4	
3	
2	**Poor**
1	
0	

Figure 2 - NBI Ratings for Bridge Condition (Caltrans, 2018).

The lowest reading from the deck, superstructure, and substructure determines the overall rating of the bridge. A bridge rated zero through four, poor condition, is considered structurally deficient. A whole bridge is considered structurally deficient when a major component is in poor condition as well. Caltrans also inspects bridges on an element level basis. California's transportation asset management plan lays out targets that prioritize preservation, rehabilitation, and replacement for bridges. Recommendations from the inspection process alert engineers when these upkeep practices are necessary.

Florida Department of Transportation conforms to FHWA standards by applying practices to vehicular bridges with a clear opening of greater than twenty feet along the direction of the roadway between abutments, arch spring lines, and extreme ends of openings for multiple boxes and pipes (FDOT, 2015). These are classified as major structures, and are primarily bridges. Culverts larger than twenty feet are also considered when complying to FHWA standards.

Previous bridge inspections are used to compare with current inspections that occur at least once every two years to determine maintenance, replacement, and rehabilitation needs. Non-scheduled inspections are directed after major weather events and/or interruptions. FDOT claims their inspection program has caused steady improvement to bridges belonging to the state highway system.

Florida has a Performance Policy and Performance Framework that assists with the decision making process (FDOT, 2015). FDOT enforces performance standards to reinforce importance and has published measures to meet performance goals. Goals include assessing how well Florida's multimodal transportation system is functioning, providing information to support and inform decision making, assessing how effectively and efficiently transportation programs, projects and services are being delivered, determining customer satisfaction levels, and demonstrating transparency and accountability to Florida’s citizens and the department’s stakeholders (FDOT, 2015). Figure 3 illustrates the framework of Florida’s performance program.

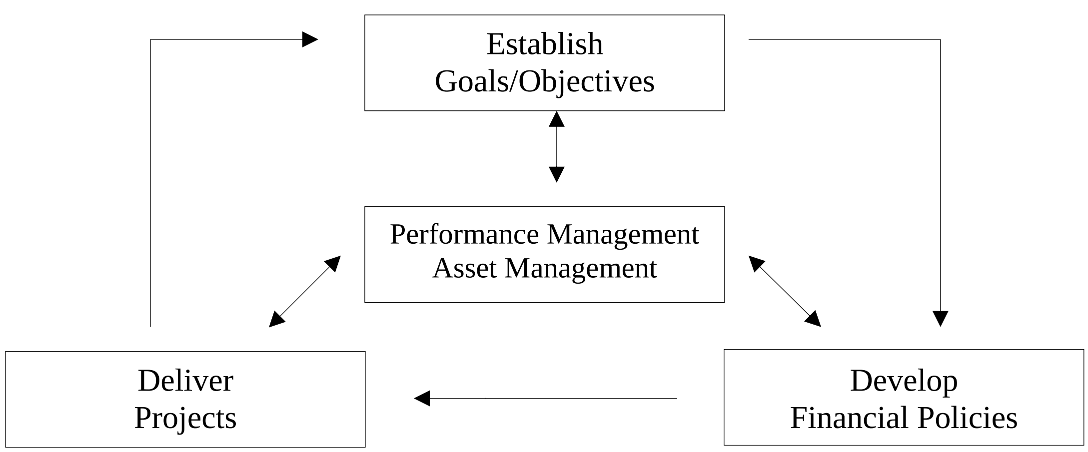

Figure 3 - Performance Based Planning and Programming Process (FDOT, 2015).

FDOT declares to take a proactive approach to bridge maintenance by focusing on preventative maintenance and repairs prior to deterioration so as to meet and or exceed life expectancy (FDOT, 2015). This type of preventative maintenance should lower the occurrence of bridge replacements. Specific standards are upheld to maintain progressive bridge health (FDOT, 2015):

- Include all FDOT-maintained bridge projects that need repair in the Bridge Work Plan within twelve months of deficiency identification as candidate projects for potential Work Program adoption
- Replace or repair all structurally deficient FDOT-maintained bridges and those bridges posted for weight restriction within six years of the deficiency identification
- Replace all other FDOT-maintained bridges designated for replacement within nine years of the deficiency identification
- Coordinate with the department's Motor Carrier Size and Weight Office and Florida Highway Patrol's Office of Commercial Vehicle Enforcement to reduce the illegal operation of commercial motor vehicles exceeding weight limits on Florida's public roads and bridges
- Continue to monitor bridges scheduled to be replaced and make interim repairs, as necessary, to safeguard the traveling public

To aide in selecting upcoming projects, a life cycle analysis is used. AASHTOWare Bridge Management Software, also known as Pontis, performs a life cycle analysis, and employs a method to weigh different project options. The program allows engineers to assess multiple projects and displays the life cycle costs to determine the most appropriate project.

The Tennessee Department of Transportation (TDOT) established performance measures in their TAMP for bridges, based upon the operations, future conditions, maintenance, and costumer input (TDOT, 2018). The department tracks the condition of their bridges within a bridge management system. TDOT also follows sufficiency ratings of its bridges determined from the condition of the bridge deck, superstructure, and substructure (TDOT, 2018). Culverts longer than twenty feet are tracked through their overall condition, and bridges are inspected biennially.

Overall, TDOT adheres to FHWA standards by rating bridges based on good, fair, or poor conditions. Bridges are also rated on a scale of zero to nine when measuring the deck, superstructure, and substructure. The condition is then determined by the lowest rating. The department has determined long-term goals for bridges to maintain a state of good repair through each bridge at the least possible cost.

Inspections are performed on the deck, superstructure, and substructure of bridges to determine the necessity for maintenance, preservation, rehabilitation, or replacement. While a sufficiency rating portrays the whole condition of inspected bridges, damage to main bridge components are able to prompt the need to perform some type of operation to prolong the life of the structure. For an NBI rating lower than six for the bridge deck, superstructure, or substructure Tennessee puts the bridge up for maintenance, while a score lower than five triggers rehabilitation or replacement of an entire bridge structure ("Tennessee Department of Transportation," 2018). Figure 4 displays a state of good repair, with no more than six percent of state owned bridges in poor condition.

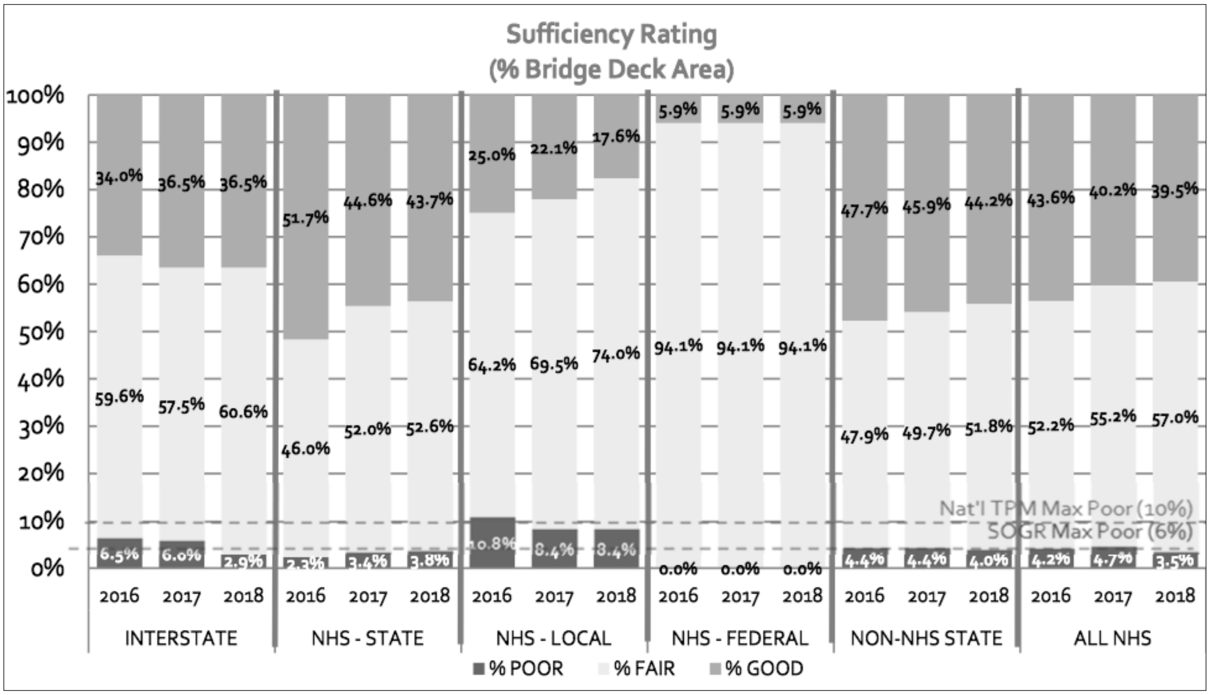

Figure 4 - Bridge Sufficiency Ratings (FDOT, 2015).

TDOT follows federal National Bridge Inspection Standards for inspections, then uploads the results to their Bridge Management System (BMS). The BMS program assists in deciding maintenance and rehabilitation actions based upon finances and performance optimization. The program analyses options, determines a life cycle cost and performance analysis from goals outlined by the department. Results from the BMS analysis and bridge inspections are used by TDOT's structures division to develop a long and short term bridge management program (TDOT, 2018). With a budget of approximately $100 million, 70% of the budget is allocated to bridge replacements, while the remaining 30% is dedicated to repairs. TDOT is then provided a final report containing results from analyses to assist with funding allocation for the structures program.

The annual structures management program consists of three types of treatments. These treatments include preservation, repair/rehabilitation, and replacement. These treatments are also defined within TDOT's BMS program when performing a life cycle cost analysis TDOT,2018).

Preservation includes actions such as repainting structural steel, vegetation removal, sweeping, deck repairs and waterproofing deck, navigation light maintenance/replacement, guardrail protection at bridge ends, object marker replacement, cleaning and sealing or replacement of expansion joints. Repair/rehabilitation are bridge deck and expansion joint repairs, spall repairs and steel repairs on superstructure, scour prevention, bearing replacements, and preventative measures such as waterproofing the deck or repainting structural steel. Replacing the superstructure is also in this repair category (TDOT, 2018). Bridges are ultimately replaced when their sufficiency rating reaches 50 or below, or if they are within the confines of a roadway improvement project.

Tennessee also focuses on four different strategies to manage assets including 'Review of NBIS inspection Reports', 'Smart Project Scoping and Selection', 'Hold the Line', and 'Not a Worst-First Program'. The structures division performs bridge inspections on all, but federally owned, bridges every two years. Bridges in need are placed onto a repair list and rated for priority on a scale of one to four to then be used when determining funding (TDOT, 2018). 'Smart Project Scoping and Selection' is the process of weighing the options between multiple bridge projects to determine whether repair or replacement is optimal. 'Hold the Line' refers to "holding" the number of structurally deficient bridges to less than 4% through good funding practices. Lastly, the allocations of funds (70% to replacement and 30% repairs/preservation) is the 'Not a Worst-First Program'.

The current bridge management system being used by Tennessee is going to be replaced with a system that has enhancements to assist in predicting the future needs to maximize use of assets while minimizing costs (TDOT, 2018).

1.2.2 *Cash Flow Analysis Methodology*

The Kansas Department of Transportation (KDOT) has implemented a Cash Availability and Forecasting Environment application, better known as CAFÉ. The system allows agency managers to detect and respond to cash flow shifts with ease and accuracy (Ferrill et al., 2012). The system stemmed from the need to respond to budget cuts and monitor their cash flow closely. The method works by using payout curves associated with project data used to predict future cash payouts. The sum of the curves provides the overall cash needs of the department. Their model is able to be accurate and adjust for bias by analyzing all of KDOT'S past projects. Their current payout model was created by analyzing all past payout scenarios. This method has allowed for a model that is able to predict what is most likely to happen and is applied to current projects. However, parameters such as start time, end time, cost estimates, and test scenarios are able to be manually altered. According to KDOT CAFÉ has been able to efficiently manage cash and predict future cash availability (Ferrill et al., 2012).

Texas Department of Transportation (TxDOT) monitors cash flows through a cash management process that also connects administrative, accounting, payment management, revenue collection, budgeting forecasting, letting, and planning/programming activities (TxDOT, 2018). Their cash forecast includes historical and projected revenues, monthly endings, and lowest daily balances. They are able to calculate future revenues by basing them off of financial analyses that includes historical trends, current statutes, the comptroller's certification revenue estimate, current events, and other resources deemed appropriate (TxDOT, 2018). Future expenditures are based upon budgets established by the General Appropriation Act, their own contract letting amounts in the ten-year Unified Transportation project, and remaining obligations on previously let projects (TxDOT, 2018). To account for inflation, the cash flow forecast adds a percentage of total cost expenditures, excluding contractor payments, to a growth expenditure line item. The cash forecast takes into account restrictions on the use of funds, timing issues, regulations, economic uncertainty, and other agency operations.

The Baumol model is best at determining an optimum cash balance when one is certain of the factors affecting the cash flow. The original model, equation one, assumed only cash outflows and the stock of cash were replaced by the sale of assets of value M, and cash outflows were assumed to be at a constant rate of c per day (Gregory, 1976).

$$M^* = \sqrt{\frac{2rc}{v}}$$ **Eq. 1 (Gregory, 1976)**

A variant of the model, equation two, allowed the cash balance to become negative, however it added the charge (u) per money unit per day of the negative balance.

$$M_o^* = M^* \sqrt{\frac{u}{v+u}}$$ **Eq. 2 (Gregory, 1976)**

Baumol's model is not perfect, as it assumed a constant environment. It also applied to only one-way cash transactions and transfers (Gregory, 1976). Although, the drawbacks could be ignored if there is a steady inflow of cash.

Patinkin's model addressed some of the failures derived from Baumol's model. The new model introduced the idea of cash flow transactions in two directions, payments and receipts (Gregory, 1976). In considering monetary demand for a specific time period receipts and payments would not be systematic, so a fixed weekly budget would be able to be kept. Patinkin's logic was that a company held a cash balance to cover all transactions up to the time of the next decision to transfer short term assets into cash (Gregory, 1976). Criticisms include the large variance in size of payments, and less frequent inflows.

The Miller-Orr model used principles from Patinkin's model. Miller-Orr is a two-asset model with cash flow transactions in both directions (Gregory, 1976). It differs from Patinkin's model because the time restriction is removed, allowing transfers between assets to occur at any time. Because of the ability for cash inputs and outputs to occur at any specified time, the cash balance is constrained to vary between two limits. Once either limit is reached, a transfer is made to return the cash balance back within the limit (Gregory, 1976). The lower value is zero, upper bound is h, and restored level after cash balance is z. The assumption is made that costs are independent of the amounts transferred. Optimal values of h and z are:

$$Z* = \left(\frac{3r\sigma^2}{4\upsilon}\right), h* = 3z* \qquad \textbf{Eq. 3 (Gregory, 1976)}$$

$$\sigma^2 = m^2t \qquad \textbf{Eq. 4 (Gregory, 1976)}$$

The optimal average cash value is as described:

$$\bar{M}* = 1/8\ \frac{4}{3}\ \left(\frac{3\gamma\sigma^2}{4\upsilon}\right) \qquad \textbf{Eq. 5 (Gregory, 1976)}$$

Criticisms of this model include the assumption of stability of cash balances in a widely unstable environment, and the strict limit parameters that may not be necessary in all situations.

Hung-Keun Park introduced a cash flow forecasting method to be used during the construction phase based on the planned earned value and the actual cost. The model uses moving weights of cost categories over the project duration. The model process is broken down into three steps. Step one involves inputting planned earned values and assigning them to each month, cost category, weights, and time lags (Park, 2004). The model also adjusts to changes based on user inputs. New weights are automatically applied to actual costs, cash in, cash out, cumulative cash flow, and capital cost in the second step. While moving weights are applied to the remainder of each period. The last step is to recalculate the planned earned values and budget for each month (Park, 2004).

Park's forecast aims to be accurate, flexible, and comprehensive. It also aims to include uncertainties to improve the preciseness of the cash forecast. The method first matches each expenditure item to a particular characteristic of operations. In construction projects, basic costs are broken down into the groups of labor, material, equipment, subcontractor, and general office overhead.

An important factor of cash flow forecasting at the project level is how to build a cash out model with time lags and cost (Park, 2004). Cash out forecasts apply time lags based upon agreements of payment. The time lags are applied to the categories of materials, labor, equipment, subcontractors, expenses, main materials, depreciation items.

Cost curves are developed to applied to project costs, by past researcher Ricardo Bacarreza. Curve one assumes the rate of expenditure is uniform during the entire project. Curve two amuse that 25% of the total cost occurs during the first half of the project, and 75% occurs in the second half. Curve three assumes that 75% occurs during the first half of the project. Unless the curves of all cost categories are uniform, relative weights should be changed when costs are incurred over the project duration. However, if weights of cost categories are uniform, curves should be straight lines (Park, 2004).

It is likely that the percentage of cost categories incurred will differ from the initial estimates. To remedy this problem, weights of cost categories relative to the remaining budget will be changed even though the forecast total cost or planning has not changed. If a change of project amount or duration has occurred due to a change order or change of contract conditions, the weights of cost categories will be changed (Park, 2004). Therefore, moving weights essentially apply different weights depending on the remaining budget of different cost categories, as well as determine weights of them over the duration of the project. These moving weights applied to cost categories of the remaining budget assist in reducing the amount of uncertainty of forecasting cash-out. The budget characteristic process is visually depicted in Figure 5.

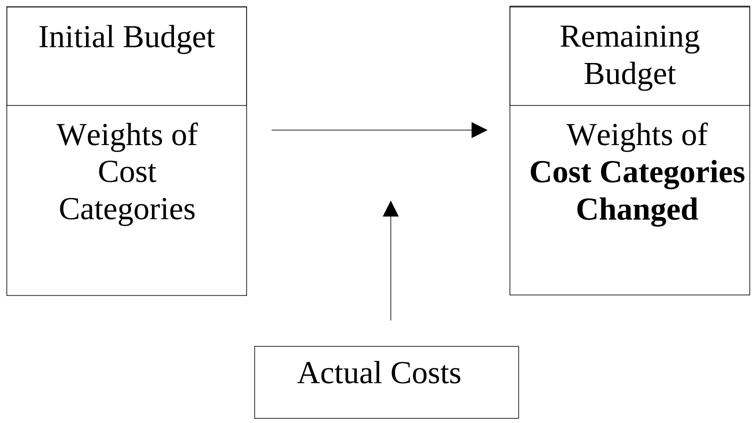

Figure 5 - Characteristic of a Budget during the Construction Period (Park, 2004).

Park's cash-in forecast takes into account the retention money and billing period on earned values (Park, 2004). Retention is calculated by taking a percentage of retention described in the contract. Monthly-earned values are transferred to the cash-in forecast.

1.2.3 *Review of Asset Valuation Practices*

The Colorado Department of Transportation (CDOT) has developed an asset valuation methodology that can be broken down into three categories. First bridges, culverts, pavement, tunnels, and walls utilize a condition based approach. A stylized formula is used to calculate current value and replacement values, that differs per structure type. Next fleet, ITS, and signals utilize a linear depreciation approach. The replacement value is the acquisition value adjusted for different factors for each structure type. While the current value is the replacement value discounted by the ratio of asset age and asset economic life. Lastly, buildings are insured values only for current value and replacement value (CDOT, 2016). All elements are then analyzed as assets and amounted to a current value and replacement value. Because of the individual valuation of assets CDOT claims to produce great depth and scope.

Indiana Department of Transportation proposes and tests out four asset valuation methods that offer different results. Methodology one is the Elemental Decomposition and Multi-Criteria Method (EDMC). The method considers the characteristics of each individual element. Asset condition and asset remaining life are represented by the condition and remaining service life of each component. This method is effective because it uses an element approach instead of the commonly used monolithic structure approach (Dojutrek et al, 2012). The replacement downtime salvage method, method two, operates on the assumption that an existing asset can be valued at any time on the basis of the costs that are avoided by not having to replace it at the time in question (Dojutrek et al, 2012). This method incorporates replacement costs, user inconvenience, and benefits of recycling. Method three, the land valuation method, determines that an asset is valued at the total worth of the land occupied by highway assets. The value of highway assets can be determined by the price of the land it sits on. This method is best for densely populated areas with high real estate prices and can act as a way of determining highway relocation. The fourth method, probabilistic valuation method, takes into account probabilistic elements. The method works by predicting the probability of surviving to the end of its service life to determine asset value based on variables of each asset.

"A comparison of Asset Valuation Methods for Civil Infrastructure" describes five main asset valuation methods to be specifically used in civil engineering practice. The methods are all condition based, as the article proclaims the simplest way to equate the user and owner to the value of the road network is through condition (Cowe Falls et al., 2004). These most commonly referenced asset valuation methods, proclaimed by the document, include book value, replacement cost, written down replacement cost, net salvage value, and GASB 34. When tested on a local city it was found that each method supplied different valuation figures. However, when analyzed using a Monte Carlo simulation the methods were statistically similar when variability in the input data is characterized using the simulation.

The methods can be further classified into past, current, or future based methods. Past-based methods use historical expenditures to determine their value. Included in this category are book value and historical cost. Current-based approaches use current data and include replacement cost, written down replacement cost, net salvage value, and deflated GASB methods. A future-based valuation method uses future values, while including market value, productivity realized value, and salvage value. While calculating current or past values may be straightforward, future value methods are more difficult.

Book value is the value of an asset based upon historical costs excluding any allowance for depreciation (Cowe Falls et al., 2004). This method includes the cost to build/acquire the asset, adjusted for consumption of that asset. Consumption references the condition of the asset to turn the historical costs to current value. If actual cost data is not available, for this method, the historical cost is calculated by adjusting the current replacement cost by historical cost factors. Consequently, historical cost is estimated.

Replacement cost is the price required to return an asset to new condition, while it is at its current market value (Cowe Falls et al., 2004). Replacement costs are based upon the current market forces, for infrastructure that is maintained or rehabilitated by bids. Replacement cost can also be predicted using trend lines, though the accuracy of the trend lines may vary in the future (Cowe Falls et al., 2004).

Written down replacement cost is the price, at its current market value, required to return an asset to new condition, adjusted for the deteriorated condition of the asset at the time of replacement (Cowe Falls et al., 2004). The method acknowledges that some assets are in better or worse condition when it is time for replacement. Therefore, the condition of the asset is used to adjust the replacement cost. Because of the difficulty in estimating future replacement costs, this method is not ideal for future predictions.

Government Accounting and Standards Board Statement 34 (GASB 34) is defined as a past based approach that estimates the historical cost using construction cost trends (Cowe Falls et al., 2004). Estimated historical costs can be calculated as deflated replacement costs adjusted for the remaining service and useful life. In this method replacement cost is deflated using a price index. This method also effectively adjusts the replacement cost for age of the asset (Cowe Falls et al., 2004). In the absence of historical costs, they are calculated by deflating current replacement costs per square foot using the FHWA Highway price index, often referred to as Deflated GASB.

The Governmental Accounting Standards Board issued Statement 34, requiring bridge owners to provide a value for all major infrastructure assets constructed after June 30,1980. California Department of Transportation, in order to comply with the statement, created a method for asset valuation. The methodology is based upon various materials, design types, and current condition of the in-state bridges ("Transportation Research Circular," 2003). When selecting the correct method Caltrans had to keep in mind their lack of electronically available construction cost information, and their available condition assessments for infrastructure assets.

Caltrans first considered three different asset valuation methods: depreciated historic cost, deflated replacement cost, and written down replacement cost ("Transportation Research Circular," 2003). However, the method of deflated historic cost was deemed invalid. Due to labor requirements it would take the review of records of construction, improvement, and maintenance projects over various years. The method also had the disadvantage of requiring a life span for bridges, which proved to be unhelpful when a bridge outlived its assumed life span.

The deflated replacement cost method would work well for Caltrans, however it did not meet all of the department’s needs. The method was believed to not adequately capture the value because it does not account for the level of preservation that the bridge has experienced over its life ("Transportation Research Circular,” 2003). The "Transportation Research Circular” poses an example with two bridges constructed in the same year, with similar deterioration times. However, the two bridges have largely different preservation operations performed. When using the deflated replacement valuation method, both of the bridges have the same asset valuation, despite the differing preservation techniques causing one bridge to be in better condition. Because of this fault Caltrans believed this method would not accurately depict the current worth of California’s infrastructure.

The remaining asset valuation method considered was the written down replacement cost method. The method intends to calculate the current replacement cost and reduce it based upon the current condition of the asset ("Transportation Research Circular,” 2003). This method had plenty of advantages. The first was that actual historic construction costs along with the year of construction are not mandatory data. The second was that the amount of preservation applied to the bridge would be taken into account. The method was deemed superior because of its methodology of taking into account the current condition of infrastructure assets.

Figure 6 depicts all three methods of asset valuation on the same bridge constructed in 1960 at a price of $1,500,000 for an assumed 60-year life. As revealed in the figure, in 2000 a replacement cost was set at $2,450,00 at 71% new condition. The historical cost method depicts linear depreciation over the lifespan of the bridge. The depreciated replacement cost method depicts linear deflation of the replacement cost back to the construction year of 1960, followed by a linear depreciation over the life span ("Transportation Research Circular," 2003). The written-down replacement method is depicted as a straight vertical line in the year 2000. Figure 6 illustrates the point that a bridge with little preservation can have an asset value significantly above the depreciated value approaches for the same year ("Transportation Research Circular," 2003).

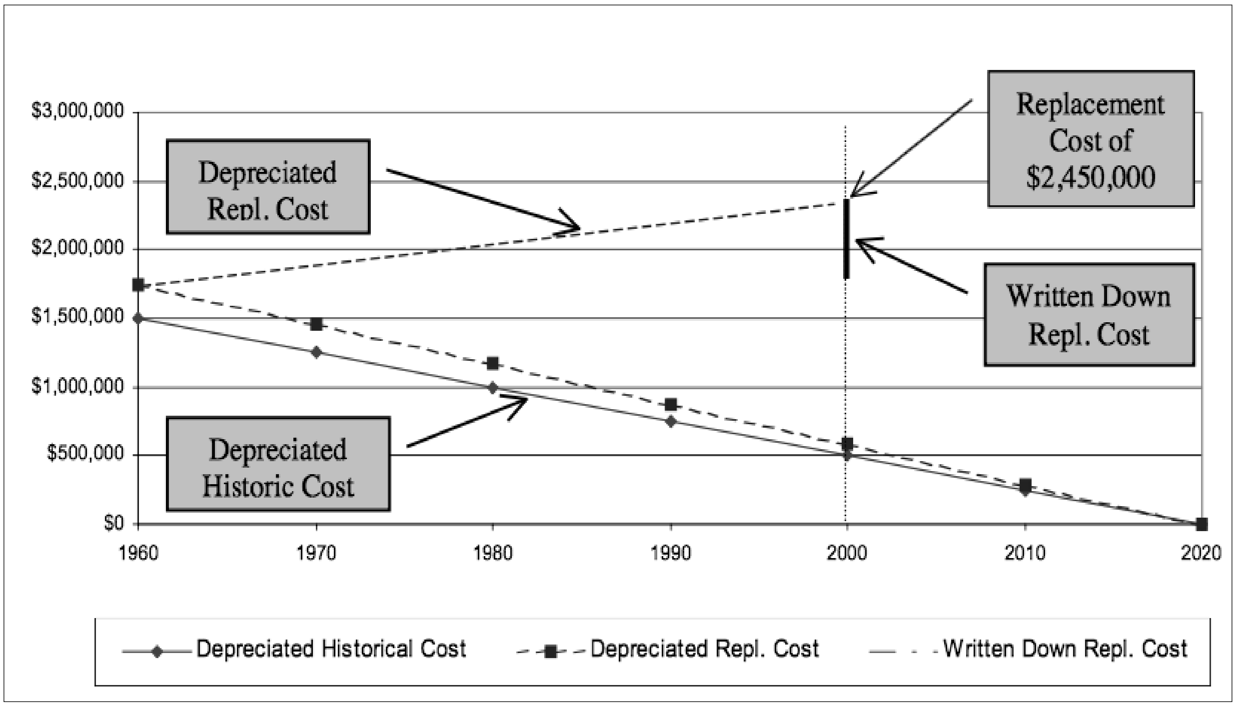

Figure 6 - Asset Valuation Approaches ("Transportation Research Circular," 2003).

Caltrans ultimately chose to move forward with the written down replacement cost method for their asset valuation approach. Thus, the current replacement value of bridges was determined dependent upon average state-wide unit replacement costs from contract bid documents. The overall current replacement cost was determined by adding the material and labor costs for replacement, to delivery costs. Replacement costs for each structure are then written down based upon the current condition of the bridge measured by the bridge health index ("Transportation Research Circular," 2003).

1.2.4 *State Use of Unit Cost Figures*

Florida Department of Transportation (FDOT) uses unit cost information to assist in determining the cost of a bridge project. They have developed the Bridge Development Report to identify the most cost effective, appropriate structure type for any site condition. The process to complete this task has been broken down by the department into three tasks, with the first task leaning heavily upon unit cost information.

The first task involves using average material costs to create an estimate for the proposed bridge project. Average material costs have been derived from FDOT historical bid data and laid out to be observed in three subcategories. The overall categories for unit cost information are defined as substructure, superstructure, and reinforcing steel determination. Each of these three subsections contains specific elements, relating back to the substructure, superstructure, or reinforcing steel, and the unit price for these elements within a specific year. Substructure includes the elements of piling and footings and goes in depth about specific types such as sheet piling or concrete piling. Substructure includes a wide variety of items including, bearing material, girders, railings and barriers, expansion joints, and retaining walls. The section for determining reinforcing steel assists in determining the quantities of reinforcing steel per cubic yard of concrete for elements such as piles, piers, slabs, and girders.

The second task is to adjust the total bridge cost for unique site conditions with the help of site adjustment factors. The cost modifications are as follows:

- Rural construction costs should be decreased by six percent
- Urban construction should be increased by six percent
- For construction over water, construction costs should be increased by three percent
- For phased construction, such as projects over traffic or requiring multiple phases to complete an entire cross section, a twenty percent premium is added to affected units of the bridge structure

The third task is to review the computed total bridge cost on a per square foot basis to then compare against historical cost ranges for similar structure types. The "similar structures" used for comparison as shown in Table 2. The goal of this task is to ensure accuracy in the cost estimating; however, if a site has unmentioned circumstances that affect the cost they should be accounted for at the discretion of the estimator. Provided by FDOT are varying historical costs for projects and low/high prices for standard bridges completed in previous and recent years.

While all of this cost information is provided in a file, updated for various years, the Florida Department of Transportation has also created an excel spreadsheet to automate the process. The process takes all of the information from the pdf file and inserted it into the excel document with spaces for the user to input quantities or unit amounts so the sheet can calculate total costs per square foot.

Table 2 - Unadjusted Bid Costs of Florida Deck/Girder Bridges (FDOT, 2009)

Project Name and Description	Letting Date	Deck Area (SF)	Cost per SF
SR 704 over I-95 (930183 & 930210)	97/98	14,804 each AASHTO Type IV Simple span	$60.66
SR 700 over C-51 (930465)	97/98	7,153 AASHTO Type II Simple Span	$46.46
SR 807 over C-51 (930474)	98/99	11,493 AASHTO Type III Simple Span	$48.77
SR 222 over I-75 (260101)	00/01	41,911 AASHTO Type III & IV	$63.59
SR 166 over Chipola River (530170)	00/01	31,598 AASHTO Type IV	$48.52
SR 25 over Santa Fe River (260112)	00/01	17,118 AASHTO Type IV	$52.87
SR 71 over Cypress Creek (510062)	00/01	12,565 AASHTO Type III	$49.64
SR 10 over CSX RR (580175)	00/01	12,041 AASHTO Type IV	$54.91
SR 291 over Carpenter Creek (480194)	00/01	7,760 AASHTO Type IV	$59.41
SR 54 over Cypress Creek (140126)	00/01	6,010 AASHTO Type III	$51.48
SR 400 Overpass (750604)	00/01	27,084 AASHTO Type VI	$48.15
Palm Beach Airport Interchange over I-95 (930485)	99/00	9,763 Steel	$85.50
Turnpike Overpass (770604)	98/99	7,733 Steel 179' Simple Span	$79.20
SR 686 (150241)	99/00	63,387 Steel	$73.31
SR 30 RR Overpass (480195 & 480196)	00/01	6,994 each	$118.35
SR 91 Overpass (over road) (750713)	06/07	38,020 AASHTO Type V	$85.82
SR 91 Overpass (over road) (754147)	06/07	18,785 Steel	$133.18
SR 25 Overpass (over railroad) (160345)	06/07	13,523 AASHTO Type III	$136.36
SR 70 Over Road (949901) Bridge Widening	06/07	3,848 AASHTO Type II	$210.92
SR 710 Over water (930534)	06/07	12,568 Inverted T-Beam 20”	$124.63

The Tennessee Department of Transportation (TDOT) provides public information pertaining to average bid prices on their website. The site contains documents of average bid prices from year 2000 up to 2017. The document references item numbers specific to TDOT and lists them with the average unit price used separated by four defining regions of the state. Along with this cost information, the documents provide the unit of measurement, total cost, and total quantity for each item listed.

The Texas Department of Transportation (TxDOT) also provides an index for unit costs throughout the year. However, the information provided from the department is more specific and selective. Within their document, the department first offers an average percent breakdown of overall project costs for bridges. This includes off/on-system span bridges and culverts. For these structures, the average percentage for structure, mobilization, removal, and approach is displayed. TxDOT then goes to lay out specific unit costs for off-system culverts, off-system span, on-system culvert, and on-system spans. Within the span categories, unit costs are listed for girders, slabs, and beams. For these elements, the number of bridges, deck area, low bid structure costs, and average unit costs are recorded for the year specified.

1.2.5 *Relative Element Weights as a Means to Predict Cost*

Florida Department of Transportation ranks its bridge elements by importance values, or “weights”. FDOT has determined this process necessary for calculating their bridge health index. Computation of the bridge health index is an aggregation of individual element condition indexes, weighted by relative importance of each element (Sobanjo et al., 2016). FDOT’s “Implementation of the 2013 AASHTO Manual for Bridge Element Inspection” details the four options Florida was presented with. This was to determine element importance weights, and the method it ultimately decided was best representative of the state's elements. These methods are based on element replacement costs, element long-term costs, vulnerability to hazard risks, and element definition in terms of class, category, or type.

Element weights based on replacement costs are originated by unit costs and then made a ratio by dividing each element cost by the overall total bridge element replacement cost. These calculated weights are then revised on a scale of zero to ninety-nine, based upon element cost data from Florida's 2009 bridge inventory (Sobanjo et al., 2016). Elements such as corrugated/orthotropic deck and concrete culvert had the highest weights, due to their high unit replacement costs. It was also found that elements with small replacement costs such as joints, bearings, and railings had small importance weights.

Element weights based upon long-term unit costs used unit costs in each elements worst condition state. A ratio is then calculated for each element's long-term cost (unit cost multiplied by the element quantity) relative to the overall bridge long-term costs (sum of element long-term costs) (Sobanjo et al., 2016). These calculated element weights were then revised on a scale of zero to ninety-nine based upon 2009 bridge inventory cost data. Costlier long-term elements such as the foundation had higher values for element weights. Once again elements such as joints, bearings, railings, and moveable bridge elements had small importance weights due to the small long-term costs.

Element weights based on vulnerability to hazards incudes natural and manmade hazards likely to occur in Florida. Bridge elements were rated, from zero to five, on their vulnerability to hazards (Sobanjo et al., 2016). Hazards included in the ratings were tornadoes and strong winds, category three hurricane on non-costal bridges, category three hurricanes on costal bridges, wildfires, flooding, truck collision, vessel collision, and overhead collision. Each of these hazards were then determined to have importance points, which established relative weights for each element. The weights are converted on a scale of zero to ninety-nine, and found that for most elements the vulnerability to hazard was high. Because all elements are vulnerable to some form of hazard.

Element weights based on BMS classification used new Bridge Management System (BMS) element definitions in terms of classification of the category and element type. National Bridge Elements (NBE) were considered to be the most important elements. Most elements within NBE were assigned the highest score of 100. Bridge Management Elements (BME), primarily joints and slabs, were assigned the score of 40. Agency Developed Elements (ADE) were further distinguished by category and element type in order for a score to be assigned (Sobanjo et al., 2016).

Importance weights developed through replacement costs, element long-term costs, and hazard vulnerability were combined to form weighted average values for element importance weights. Element long-term costs are weighted four times more important than the vulnerability index, and element replacement costs are ignored. Ultimately these combined weights, along with a few modified element weights based on FDOT engineer opinion, were used to develop final element weights for BMS implementation.

In this study, conjoint analysis, an innovative method for identifying importance weights that affect bridge deterioration and performance, will be introduced. The following subsection provides a literature review.

1.2.6 *Conjoint Analysis*

A conjoint analysis is a survey based technique that determines how people value products and services. It is able to do this by presenting individuals with options. Options chosen are then analyzed for an underlying cause of why a particular choice was made. A conjoint analysis will be able to allow individuals to understand how and why people make decisions by analyzing values derived from preference (Dobney, 2018).

The recent trend of greater patient involvement in aspects of health care services has led to more interest in patient and community opinions. The use of conjoint analyses becomes beneficial when eliciting public opinion on health care systems. A conjoint analysis will be able to determine the relative importance of different aspects of care, trade-offs between the aspects and satisfaction with services (Ryan et al., 2000). Specifically, the analysis method has been used in many different healthcare areas to show how people are willing to trade characteristics, estimate relative importance of service characteristics, and attribute importance (Ryan et al., 2000).

The article focuses on an orthodontic care study that used a conjoint analysis to compare patient preferences. It considers trade-offs patients are willing to make between location of treatment and waiting time (Ryan et al., 2000). The first step in designing the analysis was identifying the characteristics, through a policy question. The second step was assigning level to characteristics. There are three types of levels:

- Cardinal – Ex. Waiting times
- Ordinal – Ex. Levels of pain
- Categorical – Ex. No natural ordering, such as between specialist nurse, general practitioner, or consultant

The third step was the choice of scenarios. Scenarios were created by establishing all of the possible outcomes from the characteristics and levels. The fourth step was establishing preferences. The conjoint study is able to elicit preferences from patients by using either a ranking, rating, or discrete choice method (Ryan et al., 2000):

- Ranking asks recipients to list scenarios in order of their preference
- Ranting allows people to assign a score to presented scenarios. Such as from 0 to 10
- Discrete choice asks recipients choose a preferred choice over a number of other choices. Such as choosing between A or B

Discrete choice was determined to be most compatible with healthcare. The last step in the design process, step five, was the data analysis portion. For this specific analysis a regression technique was designed to work with the discrete choice data gathered. The benefit function used is described below:

$$\Delta B=\beta_1X_1+\beta_2X_2+\beta_3X_3+. . .+\beta_nX_1$$ **Eq. 6 (Ryan et al. 2000)**

ΔB is the change in benefit in moving from service A to B

X_j (j= 1,2,…,n) are the differences in attribute levels between A and B

B_j (j=1,2,….,n) are coefficients of the model that were going to be estimated

The study was performed on 160 patients that attended three orthodontic clinics. Sixteen scenarios were possible, and fifteen discrete choices were created to be presented to recipients to choose between the current service or alternative. Table 3 displays the attributes, level and regression used in the study.

Table 3 - Attributes and levels Includes in Conjoint Analysis Study (Ryan et al., 2000)

Attributes	Levels	Regression Coding
Waiting time (for first appointment) (WAIT)	4 months, 8 months, 12 months, 16 months	4, 8, 12, 16
Location of first appointment (for diagnosis) (LOC1)	Hospital, local	0=local, 1=hospital
Location of second appointment (and subsequent appointments for fixing the appliance) (LOC2)	Hospital, local	0=local, 1=hospital

To maintain consistency, the study excluded participants that were inconsistent in their choosing's or had dominant preferences. For those considered consistent a benefit equation was estimated (Ryan et al., 2000):

$$\Delta B = \beta_1 LOC1 + \beta_2 LOC2 + \beta_3 WAIT$$ **Eq. 7 (Ryan et al. 2000)**

ΔB is the change in benefit in moving from the current service to an alternative

β_1 to β_3 expresses the relative importance of the different attributes

Results identify that respondents prefer a local clinic to a hospital. Moving from a hospital clinic to a local clinic will increase benefit by 0.77 for the first appointment and 0.91 for the second appointment. Coefficient results for variables are exhibited in Table 4. Ryan et al. interprets coefficient value meanings, "The negative coefficient of 0.59 means that a unit increase in waiting time will reduce the benefit score by 0.59. Individuals are willing to wait an extra 1.3 months (0.77/0.59) to have a local clinic for their first appointment and an extra 1.5 months (0.91/0.59) to have a local clinic for their second appointment" (Ryan et al., 2000). The score from the benefit equation, of having moved from current to local for first and second appointments while waiting 12 months, is -2.28.

Table 4 - Results from Regression Analysis (Ryan et al., 2000)

Variable	Coefficient	P Value
Waiting time*	−0.59	<0.001
Location of first appointment (0=local, 1=central)	−0.77	<0.001
Location of second appointment (0=local, 1=central)	−0.91	<0.001
Log likelihood	−1220	
$\chi 2$	319.49	
McFadden R^2	0.12	

Table 5 is an example of choices respondents were asked to choose between for the current and alternative options. For each choice they could choose between definitely (a), probably (a), no preference, probably (b), and definitely (b).

Table 5 - Example of Conjoint Analysis Question (Ryan et al., 2000)

	(a) Current			(b) Alternative		
	First appointment	Second appointment	Waiting time	First appointment	Second appointment	Waiting time
Choice 1	Hospital	Hospital	8 months	Local	Local	12 months
Choice 2	Hospital	Hospital	9 months	Hospital	Hospital	16 months
Choice 3	Hospital	Hospital	10 months	Local	Local	16 months

Australia's tertiary education sector is changing due to factors such as lowered government funding, number of university attendees, and faster loan repayment schemes. A conjoint analysis was conducted to focus on recent high school leavers entering university. The analysis aims to determine preferences that students will consider most important, and the trade-offs they would make between different attributes. An understanding of the trade-off process and relative importance for different factors will assist universities in marketing strategies (Soutar et al., 2002). The study states this as its goals for the research study:

- The major factors that influence high-school leavers' university preferences
- The relative importance they attach to these factors
- Whether there were groups of school-leavers for whom different factors were more important

A form of conjoint analysis called Adaptive Conjoint Analysis (ACA) was chosen to be used for the study. Because ACA is able to accommodate a large number of attributes, it will be able to capture trade-offs more easily. ACA is a computerized process, and is able to adapt questioning based upon the answers respondents make (Soutar et al., 2002). Software used to create the analysis was developed by Sawtooth. The sample of students evaluated in the study came from both government and non-government high schools in their final year. Table 6 indicates the attributes selected to be in the study and the levels used.

Table 6 - Conjoint Attributes and Attribute Levels (Soutar et al., 2002)

Attribute	Level
Type of university	Is a new/modern university
	Is an old/traditional university
	Is a technological university
Ability to transfer	Offers the ability to articulate/transfer units between TAFE and university
	Does not provide the ability to articulate/transfer units between TAFE and university Is close to home less than 10km)
Distance from home	Is close to home, less than (10km)
	Is a moderate distance from home (10-20km)
	Is far from home over (20km)
Academic reputation	Has a poor academic reputation
	Has an average academic reputation
	Has a strong academic reputation
Quality of teaching	Has average quality of teaching
	Has very good quality of teaching
Job prospects	Would equip me with qualifications that provide average job prospects
	Would give me qualifications that provide good job prospects
Family opinion	Is held in good opinion by my family
	Is a university of which my family holds no opinion
	Is held in poor opinion by my family
Friends	Is where my friends will be going
	Is not where my friends will be going
Campus atmosphere	Has very little campus atmosphere
	Has a great campus atmosphere
Course suitability	Offers a course that is more or less what I want
	Offers courses that are not really what I want
	Offers a course that is just what I want

The software led students through four stages of the decision process (Soutar et al., 2002):

- Students were asked to rate how suitable different types of university were
- Students were tasked with considering the importance each attribute holds when choosing between universities, where all other attributes were the same
- Based on the responses of the above bullet points, students were presented with different hypothetical universities to consider. Two universities were described in terms of

combinations of attributes. Students were asked to designate which university they would prefer and the strength of the preference

- Students were presented with hypothetical universities and asked to consider how likely it would be that they would choose each university if it was currently available

Table 7 illustrates relative utilities and importance for each attributes in the results. Average utility score defines how desirable an attribute is. Therefore, a greater score implicates a higher performance for that attribute. Relative importance implicates the level of importance placed upon attributes relative to other attributes. The study concluded that marketing strategies could be broader because there were no outlying segments of students whose preferences differed from the majority of other students. The study concluded that the four most important determinants of university preference in Western Australia were course suitability, academic reputation, job prospects, and teaching quality (Soutar et al., 2002). The conjoint analysis was able to deliver understandings on students' decision-making process and their preferences. The data will assist marketers in understanding trade-offs between competing qualities.

Table 7 – Conjoint Analysis Results (Soutar et al., 2002)

Attribute	Relative Importance (%)	Level	Average Utility
Course suitability	15	Offers a course that is more or less what I want	116
		Offers courses that are not really what I want	64
		Offers a course that is just what I want	1
Academic reputation	12	Has a poor academic reputation	95
		Has an average academic reputation	51
		Has a strong academic reputation	1
Job prospects	12	Would equip me with qualifications that provide average job prospects	92
		Would give me qualifications that provide good job prospects	0
Quality of teaching	11	Has average quality of teaching	87
		Has very good quality of teaching	2
Campus atmosphere	10	Has very little campus atmosphere	75
		Has a great campus atmosphere	1
Type of university	9	Is a new/modern university	44
		Is an old/traditional university	13
		Is a technological university	50
Distance from home	8	Is close to home less than (10km)	58
		Is a moderate distance from home (10-20km)	34
		Is far from home over (20km)	5
Family opinion	8	Is held in good opinion by my family	61
		Is a university of which my family holds no opinion	32
		Is held in poor opinion by my family	5
Ability to transfer	8	Offers the ability to articulate/transfer units between TAFE and university	62
		Does not provide the ability to articulate/transfer units between TAFE and university Is close to home less than 10km)	1
Friends	7	Is where my friends will be going	52
		Is not where my friends will be going	2

To better understand what online shoppers prefer out of their experience, and what attributes are most important when shopping online Schuapp and Bélanger performed a conjoint analysis study. The study focused on online consumer satisfaction, as customer satisfaction is the key to returning customers and continued service relationships. The research study prides itself on its more in-depth analysis of e-satisfaction determinants, by having consumer's asses the Internet as a whole (Schaupp et al., 2005). The study is also said to be more realistic when depicting consumer's decision making processes due to the evaluation of several measures simultaneously.

Three main categories of technology, shopping, and individual product factor were selected, to then be expanded upon. Technology pertains to website usability, enabling users to make purchases. Within this specific factor the analysis looks into security, usability and site design, and privacy. Shopping covers how the buyer feels during and after shopping online. Within this factor convenience, trust and trustworthiness, and delivery are further analyzed. The product factor is the actual qualities of the product or service being sold. This factor goes into detail on merchandising, product value, and product customization. Table 8 lays out all of the factors visually. All of the major and expanded upon factors help assess the customer's online satisfaction.

Table 8 - Determinants of E-Satisfaction (Schaupp et al., 2005)

Category	Question	Feature	Attributes		
Technology	1	Security	Encryption	Accounts with IDs and passwords	Confirmation screen
	2	Privacy	Privacy statement	Policy on information selling	Use of cookies
	3	Usability	User-friendly interface	Adequate search capability	Interactive site
Shopping	4	Convenience	Ease and fun of shopping	Post purchase service	Price/product comparisons
	5	Trust	Faith in merchant and system	Reliability and integrity	Minimization of worries & regrets
	6	Delivery	Minimization of delivery time	Awareness of potential delays	Tracking number
Product	7	Merchandising	Extensive assortment	Exclusive and specialty products	Seasonal products
	8	Product Value	Customer gratification	Product quality	Overall cost
	9	Customization	Customizability	Online configurations	Number of options

A conjoint analysis was chosen as the best study to analyze these factors because it will determine how consumers develop preferences, and measure trade-offs when making decisions. The conjoint analysis also has the advantage of measuring consumer preference for attribute levels, more realistic decision modeling, and not making assumptions about relationships between attributes and the dependent variable (Schaupp et al., 2005). A basic formula is used in this conjoint analysis to determine an overall rating that portrays the effects the levels of variable have on the dependent variable:

$$Y = b_1 + b_2 + b_3 + ... + b_n + \text{constant} + \varepsilon$$ **Eq. 8 (Schaupp et al., 2005)**

Y is the respondent's preference for the product concept

$b_{i,}$ beta weights (utilities) for the features

ε is an error term

Six principle states were taken and applied to this conjoint analysis:

- This study chose the part-worth model over the vector and ideal point models. The vector model approximates the fewest parameters using a linear functional format. Part-worth estimates the largest number of parameters, because of its general functional form. The ideal point model is considered to be in between the other two models.
- Data collection methods were chosen between the two-factor-at-a-time procedure and the full profile procedure. In the two-factor-at-a-time method attributes are considered as pair wise and consumers are tasked with ranking combinations of each pair of factor levels from most to least preferred (Schaupp et al., 2005). Full-profile approach utilizes all of the factors and takes into consideration the environmental correlation between factors.
- A construction of stimuli to use in the full profile method is next. The expanded features from technology, product, and shopping were to be rated on a ten-point scale from "completely unacceptable" combinations to "perfect" combinations.
- The stimulus, attributes, were presented first with an example question and the remaining analysis questions were to be answered in a spreadsheet.
- The dependent variable can be measured metric (ratio scales) or non-metric (paired comparisons) and order ranks. Metric was used in this conjoint analysis.
- The estimation method used was least squares, because it is able to provide standard error.

The sample was comprised of 188 undergraduate students, of average age twenty-two. The data was analyzed using a software program, SPSS 11.5. Part-worth's were scaled to an arbitrary constant within each attribute. The part-worth of one level within each attribute was arbitrarily set to zero to estimate the remaining levels contrastingly. For example, encryption, within the technology was set to zero, for confirmation screen, and so on to be compared with it (Schaupp et al., 2005). The results from the technology section are shown below in Figures 7 through 9. As can be observed, in Table 9, within the security sector confirmation screen was found to be the most important level in customer satisfaction. Within the privacy attribute, privacy statement was most important. Within the usability attribute, searching capabilities were found to be most important.

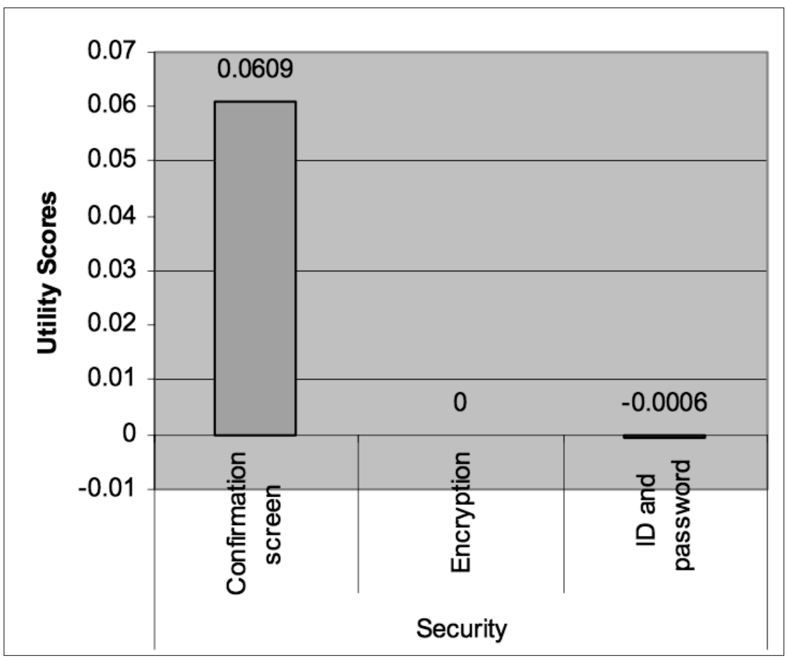

Figure 7 - Average Technology Factor Utility Scores (one) (Schaupp et al., 2005).

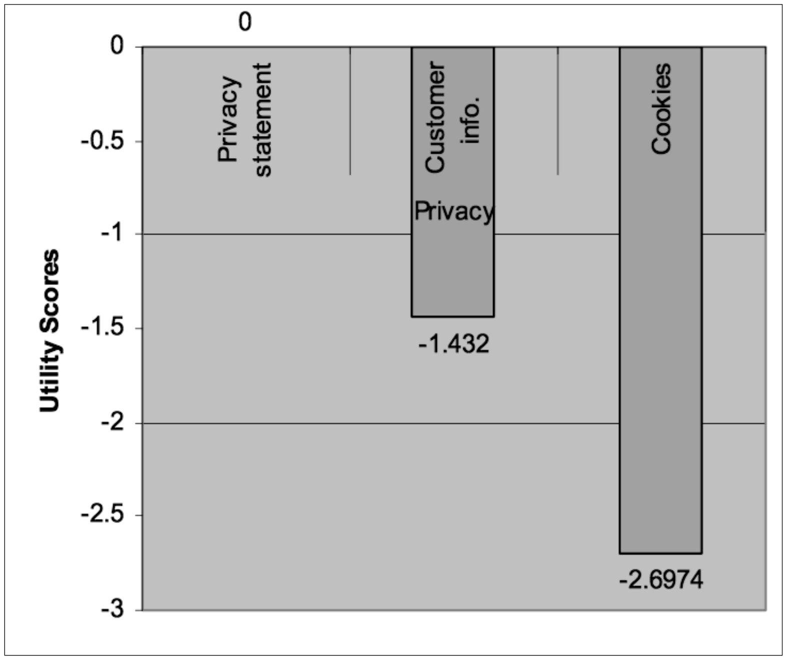

Figure 8 – Average technology factor utility Scores (two) (Schaupp et al., 2005).

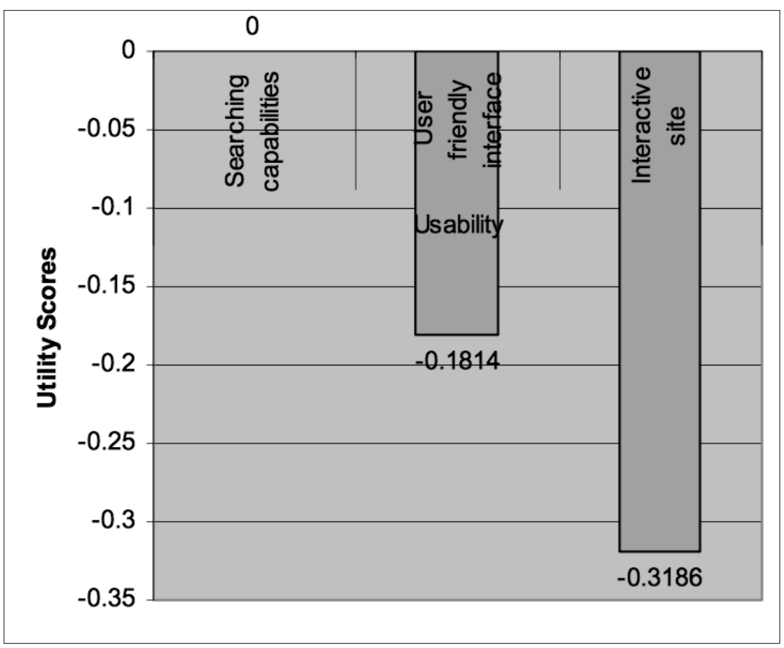

Figure 9 - Average Technology Factor Utility Scores (three) (Schaupp et al., 2005).

Table 9 - Results for Technology Factors (Schaupp et al., 2005)

Factor	Attribute	Part Worth
Security	Confirmation screen	0.0609
	Encryption	0.0000
	ID and Password	-.0006

1.3 Problem Statement

Being aware of the amount of money spent on infrastructure is important for managing GDOT's maintenance budget and maintaining the public's equity. It is common practice to take the worst first approach and repair major elements of a bridge or to allow it to deteriorate to a point where it ultimately needs to be replaced, and maintenance is no longer possible. However, keeping track of the amount of money spent (investment), current monetary value, and accurate inspection ratings helps bridges stay in their best condition while also optimizing the budget of the governing body in control of the infrastructure. Therefore, it is in the best interest of the state of Georgia to evaluate the current monetary value of infrastructure.

The research is aimed at identifying importance attributes for an accurate, yet practical, representation of a bridge's health and valuation. Multiple techniques are studied to define a bridge asset's value which meaningfully reflects the structural health condition. The study used maintenance cost data from the Georgia Department of Transportation to determine an asset valuation method that would work best for the bridges. Techniques include collection of element based costs, a cash flow analysis, and a conjoint analysis. The cash flow analysis and collection of element based costs used GDOT maintenance and NBI data to log the changing costs of bridge elements and maintenance budgets. The conjoint analysis was designed to determine factors that most affect the bridge's health. All techniques utilized played a role in defining Georgia's infrastructure value through the use of rehabilitation data.

The research will have the significance of being able to assess the value of bridges on the basis of engineering decisions, and assist GDOT in achieving their desired state of repair for their long term transportation asset management plans. A strong bridge asset management program will help extend the life of assets and decrease the amount of depreciation.

1.4 Objective and Scope of Study

The goal of this study is to develop an asset valuation approach by applying bridge cost data gathered from inspections and maintenance activities within GDOT. Asset valuation will be able to be achieved through the use of weighting factors developed from a conjoint analysis, and application of maintenance data through a cash flow analysis and element cost database. Element-based inspections have not been commonly used for asset valuation; and therefore, methods have not been thoroughly explored for the process. Similar to many other Department of Transportation's practice, depreciation (or performance prediction) curves have been developed from condition states reported in the NBI inspection data. The research uses data from both inspection methods to obtain the full picture of Georgia's infrastructure. The ultimate goal of the research is to allow GDOT to document the benefit investment in infrastructure has on bridges in Georgia. Asset valuation, depreciation models, and rehabilitation cost analyses will help document the lowering of depreciation curves and preserving public equity through these techniques.

The study addresses challenges many state DOTs face and are confronted by long-term asset management. Therefore, the study considers asset valuation on a small and large scale. On a small scale, an element by element approach is taken, and multiple sources are utilized to form a cohesive picture of a bridge’s worth. Unit cost data, by element, is recorded to analyze the trend of element costs over a 17-year span. Furthermore, a cash flow analysis will visually indicate how much money has been invested in a single bridge, and determine the current value of that bridge asset. On a large scale, values will be devised to easily adjust all health indexes for factors not taken into account when determining the health index score. A conjoint analysis is used to elicit perspective on factors that most negatively affect a bridge’s performance. From this, adjustment factors are determined and applied to the health index in order to weigh the value of bridges. Details of this process are contained in Sections 3.2 and 3.4.

1.5 Summary of Chapters

This thesis consists of six chapters. Chapter 1 introduces the concept of an Asset valuation and provides the reader with important background information on the topic. The chapter also introduces the basis of the research being conducted, as well as addresses the problem statement and scope of the research at hand. Chapter 2 explains the process taken to accomplish research goals and tasks. It describes specifically the collection of element based costs, element asset valuation, conjoint analysis, depreciation of bridge assets reflecting element conditions, and a cash flow analysis. Chapter 3 addresses the analysis of methods completed in the previous chapter, to come to an overall conclusion about the conjoint analysis results. An analysis of the application of conjoint analysis results is discussed. Chapter 4 discusses results from the asset valuation techniques described in the methodology section. An analysis on the topics of cost data collection, bridge asset valuation, bridge depreciation using MHI, and cash flow analysis are included. Chapter 5 covers an overall discussion and suggestions for future work. Chapter 6 contains overall recommendations and conclusions on how the research results should be used. Chapter 7 covers all references mentioned throughout this thesis.

2. METHODOLOGY

2.1 Collection of Element Based Costs

Unit cost information relevant to elements deemed most used in Georgia were determined to be an important part of the asset valuation process. Unit cost is the expense of one unit of product, and can be multiplied by a product's total unit measurement to obtain the total price of the product. The collection of unit costs would help in estimating future bridge costs, predicting future price trends, and analyzing replacement or repair methods on an element-by-element basis. Therefore, element unit cost information was collected over a 17-year period, from 2001 to 2018. However, the database does extend multiple years out from 2018 in anticipation of predictions of future unit costs. Element unit cost data was collected by deciphering price data from GDOT and gathering other DOT's available information. The task took extensive research work, as Georgia did not have an available database in which unit costs for elements were actively collected and updated throughout the years. Therefore, the database was built from scratch and the unit costs used to fill the database for multiple elements over multiple years was all found through comprehensive research on Southern state price trends, searching through Georgia bridge maintenance projects, and NBI figures.

While over five hundred bridge elements exist, eighty-five elements were selected to be included in the element cost database as they most pertained to the state of Georgia. These elements were deemed to be the most relevant elements that are commonly referenced during Georgia bridge construction and maintenance. A list of these elements are provided in Figure 10. They are broken up into the subcategories of decks and slabs, girders, stringer, trusses/arches, floor beams and miscellaneous superstructure elements, abutments, piles/pier caps/ footings, culverts, joints, bearings, railings, wearing surfaces, and protective coatings. Each of these subcategories also has an assigned unit of measurement.

Reinforced Concrete Deck	Decks and Slabs
Prestressed Concrete Deck	
Prestressed Concrete Top Flange	
Reinforced Concrete Top Flange	
Steel Deck with Open Grid	
Steel Deck with Concrete Filled Grid	
Steel Deck with Corrugated/Orthotropic/Etc	
Timber Deck	
Reinforced Concrete Slab	
Timber Slab	
Other Deck	
Other Slab	
Steel Closed Web/Box Girder	Girders
Prestressed Concrete Closed Web/Box Girder	
Reinforced Concrete Closed Web/Box Girder	
Other Closed Web/Box Girder	
Steel Open Girder/Beam	
Prestressed Concrete Open Girder/Beam	
Reinforced Concrete Open Girder/Beam	
Timber Open Girder/Beam	
Steel Stringer	Stringer
Prestressed Concrete Stringer	
Timber Stringer	
Steel Truss	Trusses/Arches
Timber Truss	
Steel Arch	
Reinforced Concrete Arch	
Masonry Arch	
Steel Main Cables	Floor Beams & Misc. Super. & Misc. Super. Elements
Steel Floor Beam	
Reinforced Concrete Floor Beam	
Timber Floor Beam	
Steel Pin and Pin & Hanger Assembly or both	
Steel Gusset Plate	
Steel Column	Columns/Pier Walls
Other Column	
Prestressed Concrete Column	
Reinforced Concrete Column	
Timber Column	
Reinforced Concrete Pier Wall	
Other Pier Wall	
Masonry Pier Wall	
Reinforced Concrete Abutment	Abutments
Timber Abutment	
Masonry Abutment	
Other Abutments	
Steel Abutment	

Reinforced Concrete Pile Cap/Footing	Piles/Pier Caps/Footings
Steel Pile:	
1. 14 x 73 H Section	
2. 14 x 89 H Section	
3. 20 Pipe Pile	
4. 24" Pipe Pile	
5. 30" Pipe Pile	
Prestressed Concrete Pile	
Reinforced Concrete Pile	
Timber Pile	
Other Pile	
Steel Pier Cap	
Prestressed Concrete Pier Cap	
Reinforced Concrete Pier Cap	
Timber Pier Cap	
Other Pier Cap	
Steel Culvert	Culverts
Reinforced Concrete Culvert	
Other Culvert	
Masonry Culvert	
Prestressed Concrete Culvert	
Strip Seal Expansion Joint	Joints
Pourable Joint Seal	
Compression Joint Seal	
Assemble Joint with Seal	
Open Expansion Joint	
Assemble Joint without Seal	
Other Joint	
Elastomeric Bearing	Bearings
Movable Bearing	
Enclosed/Concealed Bearing	
Fixed Bearing	
Pot Bearing	
Disk Bearing	
Other Bearing	
Metal Bridge Railing	Railings
Reinforced Concrete Bridge Railing	
Timber Bridge Railing	
Other Bridge Railing	
Masonry Bridge Railing	
Wearing Surfaces	Wearing Surf. Protective Coat. etc.
Steel Protective Coatings	
Concrete Protective Coatings	

Figure 10 **– Description of Georgia Bridge Elements.**

2.1.1 *Element Cost Database*

To collect unit costs for the selected eight-five elements, a database was set up within excel to perform such a task. Figure 12 displays the element cost database, filled with price information color coordinated using the legend in Figure 11. The element cost database was decided to be created within excel because of the ability to easily update changing costs and the ability to track future unit costs using its linear prediction capabilities. The file was set up to contain the selected elements, category of each element, units, and years. The elements, category, and units are set up vertically on the left side of the file while the years are across the top of the database. This allows for each element to have a documented unit cost from 2011 to 2018. To keep track of all unit cost information entered into the database, costs are coordinated based upon their cell color. Different colors represent a different Department of Transportation entity.

	FDOT Structures Design Guidelines - BDR Cost Estimating	Replacement/New Bridge Cost Estimate
	GDOT Files	Maintenance and New Costs
	Tennesee Department of Transportation Average Bid Prices	Avg Bid Price
	FDOT Implementation of AASHTO Manual	Replacement Costs

Figure 11 – Unit Cost Database Legend.

EN	Description	Category	Unit	Element construction cost in $																		
				2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Concrete Including Reinforcement Steel		Cubic Yard																			
	1. Class A													716.18	900.82	938.60	893.25	1146.00	1995.72	1128.50		
	2. Class B														593.00				1500.00		899.00	
12	Reinforced Concrete Deck																					
13	Prestressed Concrete Deck																					
15	Prestressed Concrete Top Flange																					
16	Reinforced Concrete Top Flange																					
28	Steel Deck with Open Grid																					
29	Steel Deck with Concrete Filled Grid	Decks and Slabs	Area (sq. ft.)													84.00			83.00			
30	Steel Deck with Corrugated/Orthotropic/Etc																					
31	Timber Deck		Length (ft.)														90.26					
38	Reinforced Concrete Slab																					
	1. Simple Span																160.00					
	2. Continuous																					
54	Timber Slab																					
60	Other Deck																					
65	Other Slab																					
102	Steel Closed Web/Box Girder																					
104	Prestressed Concrete Closed Web/Box Girder																					
	1. Box Beam 12" x 36"							120.95			150.00	125.67										
	2. Box Beam 15" x 36"													211.00					194.00			
	3. Box Beam 17" x 36"							148.13	130.00	147.13	150.09	150.86	206.02	175.00	179.44	156.55	201.29	193.96	244.67	218.57		
	4. Box Beam 17" x 48"										170.00											
	5. Box Beam 18" x 36"							145.00		147.94		133.56	177.43		217.89				197.00	250.00		
	6. Box Beam 18" x 48"												174.00									
	7. Box Beam 21" x 36"			91.61				120.65	112.00	126.18	165.00	166.66	243.00	220.55	162.24	200.25		215.25		140.00		
	8. Box beam 21" x 48"								165.00													
	9. Box Beam 24" x 26"									140.00												
	10. Box Beam 24" x 36"			115.63				127.77		131.51	384.32	159.33	183.50	211.10	157.21	187.70	200.00		221.78			
	11. Box Beam 24" x 48"																			235.00		
	12. Box Beam 27' x 36"			93.84					161.42	166.00		144.65	160.25	188.00	167.16		152.95		203.00	238.86		
	13. Box Beam 27" x 48"												350.00						353.00			
	14. Box Beam 30" x 36"			113.38					140.00		201.00	167.00	250.00	198.82	176.07	225.00						
	15. box beam 30" x 48"							180.00				162.00	115.00						385.00			
	16. Box Beam 33" x 36"							141.51	135.00	150.00		200.00	185.63	227.00	194.41			476.00				
	17. Box Beam 33" x 48"			135.00					150.00		200.00		194.00							395.00		
	18. Box Beam 36" x 36"		Length (ft.)	115.00				135.43	158.00	136.21	227.54	173.39	193.26	201.73	221.00	159.94		599.00	270.00	300.12		
	19. Box Beam 36" x 48"	Girders										228.28		275.00		200.00						
	20. Box Beam 39" x 36"								174.00		236.00	211.48	176.35	239.44	164.33							
	21. Box Beam 39" x 48"								205.00	200.00		226.00	228.00				232.00					
	22. Box beam 42" x 36"										180.00	291.50		257.75	226.00					595.00		
	23. Box beam 42" x 48"							213.78	260.00		160.00		228.00	197.47					253.00			
	24. Box Beam 45" x 48"												210.00									
	25. Box beam 48" x 48"							185.00	285.23		170.00	265.00	257.00	225.00				278.75				
	26. box beam 54" x 48"							230.00														
105	Reinforced Concrete Closed Web/Box Girder																					
106	Other Closed Web/Box Girder																					
107	Steel Open Girder/Beam																					
109	Prestressed Concrete Open Girder/Beam											3141.43										
	1. AASHTO Type I			55.00				68.66	115.00	88.93			103.39	152.00	156.36	147.79			207.39			
	2. AASHTO Type II			85.00				68.51	97.09	108.50	105.99	103.18	117.78	134.21	130.00	113.86	141.07	129.32	159.34	150.17		
	3. AASHTO Type III			79.43				122.22	122.21	139.33	158.19	133.85	112.12	136.99	132.14	149.06	125.00	155.88	170.56	190.71		
	4. AASHTO Type IV			100.00				116.64	153.00	181.77	160.03	182.79	160.87	202.82			250.00					
	5. AASHTO Type V																					
	6. AASHTO Type VI																					
110	Timber Open Girder/Beam																					
111	Steel Box Girder (unspecified colsed/open)		Pound (lb.)				1.32			1.70	2.00	2.15						1.95			1.95	

Figure 12 - Unit Cost Database (A).

EN	Description	Category	Unit	Element construction cost in $																		
				2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
113	Steel Stringer																					
115	Prestressed Concrete Stringer	**Stringer**	**Length (ft.)**																			
117	Timber Stringer																					
120	Steel Truss											126.57	121.96									
135	Timber Truss																					
141	Steel Arch																					
144	Reinforced Concrete Arch																					
	1. Pipe arch 22" x 13"							44.03	59.59		52.00	62.30		48.70		145.85		96.40	98.87			
	2.Pipe arch 29" x 18"									52.97		53.40	47.15	54.65	69.00		75.00					
	3. Pipe arch 30" x 18"	**Trusses/Arches**	**Length (ft.)**	50.61																		
	4. Pipe arch 36" x 23"							59.00		64.31	71.58	66.00		72.00								
	5. Pipe arch 44" x 27"									87.38	117.38	86.00	115.00		125.00							
	6. Pipe arch 51 " x 31"										101.14	133.00		120.90								
	7. Pipe arch 58" x 36"									125.57	154.00	140.00						190.00				
	8. Pipe arch 65" x 40									213.00	285.00	162.00				235.00						
145	Masonry Arch																					
147	Steel Main Cables		**Length (ft.)**																			
152	Steel Floor Beam	**Floor Beams &**	**Length (ft.)**																			
155	Reinforced Concrete Floor Beam	**Misc. Super. &**	**Length (ft.)**																			
156	Timber Floor Beam	**Misc. Super.**	**Length (ft.)**																			
161	Steel Pin and Pin & Hanger Assembly or both	**Elements**	**Each**																			
162	Steel Gusset Plate		**Each**																			
202	Steel Column		**Each**																			
203	Other Column		**Each**																			
204	Prestressed Concrete Column		**Each**									43122.08										
205	Reinforced Concrete Column	**Columns/Pier**	**Each**									26591.96										
206	Timber Column	**Walls**	**Each**																			
210	Reinforced Concrete Pier Wall		**Length (ft.)**																			
211	Other Pier Wall		**Length (ft.)**																			
213	Masonry Pier Wall		**Length (ft.)**																			
215	Reinforced Concrete Abutment											4509.25										
216	Timber Abutment																					
217	Masonry Abutment	**Abutments**	**Length (ft.)**																			
218	Other Abutments																					
219	Steel Abutment																					

Figure 12 – Unit Cost Database (B).

EN	Description	Category	Unit	Element construction cost in $																		
				2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
220	Reinforced Concrete Pile Cap/Footing		Length (ft.)																			
225	Steel Pile:		Length (ft.)																			
	1. 10 x 42 H Section														31.92	44.15	50.69	50.38	46.08			
	2. 12 x 53 H Section														39.57	41.62	63.83	60.00	68.04	116.85	56.75	
	3. 14 x 73 H Section						35.00			65.00		65.00			52.65	54.28	72.18	77.63	65.27	66.35	106.00	
	4. 14 x 89 H Section						38.00			75.00		75.00			61.79	86.95	72.67	90.00	74.90	88.67	98.75	
	5. 14 x 102 H Section																78.15	99.00	82.00	90.00		
	6. 10" Pile			17.23	17.07	22.16	23.92	27.00	29.38	37.61	49.08	36.91	35.62	40.33	41.16	39.44	42.78	37.98				
	7. 12" Pile			19.46	23.42	22.88	27.05	59.13	42.58	41.16	55.28	42.59	40.06	60.96	53.19	42.24	48.33	47.17				
	8. 14" Pile			24.00	30.00			29.38		67.00			65.00			75.00		72.00				
	9. 18" Pile			45.00																		
	10. 14" Pipe Pile					31.00						52.74	50.00	68.00	56.06	59.00						
	11. 16" Pipe Pile			35.33	35.33	32.78						57.22	73.72	73.23								
	12. 18" Pipe Piles				35.00	41.49	69.03	74.34		78.00	75.00	61.39	67.41				96.04					
	13. 20" Pipe Pile						84.00			90.00		90.00	105.00	99.00				110.00			125.00	
	14. 22" Pipe piles											75.00										
	15. 24" Pipe Pile						90.00			96.00		96.00	100.00					140.00			145.00	
	16. 30" Pipe Pile						152.00			160.00		160.00						160.00			200.00	
226	Prestressed Concrete Pile:		Length (ft.)																			
	1. 14" Piling (no batter specification)													46.00	40.00	56.13	64.06	57.93	73.00	59.16		
	a. Driven Pumb or 1" Batter																	80.00				
	b. Driven Battered																	110.00				
	2. 16" Piling (no batter specification)	Piles/Pier Caps/Footings												47.00	51.92	53.75	52.80	34.00	85.00	61.95		
	a. Driven Pumb or 1" Batter																					
	b. Driven Battered																					
	3. 18" Piling (no batter specification)			25.00	31.92	57.35	33.83			35.00	50.00	58.34			56.38	65.23	72.00	73.14	90.50		112.50	
	a. Driven Pumb or 1" Batter						38.00	55.00		75.00		80.00						80.00				
	b. Driven Battered						47.00	60.00		85.00		90.00						110.00				
	4. 20" Piling (no batter specification)														74.03	72.55		80.00				
	a. Driven Plumb or 1" Batter																					
	b. Driven Battered																					
	5. 24" Piling (no batter specification)															90.30						
	a. Driven Plumb or 1" Batter						53.00	75.00		95.00		105.00						90.00				
	b. Driven Battered						67.00	85.00		110.00		120.00						130.00				
	6. 30" Piling (no batter specification)																					
	a. Driven Plumb or 1" Batter						63.00	100.00		150.00		150.00						120.00				
	b. Driven Battered						80.00	110.00		160.00		160.00						175.00				
227	Reinforced Concrete Pile		Each																			
228	Timber Pile		Each																			
229	Other Pile		Each																			
231	Steel Pier Cap		Length (ft.)																			
233	Prestressed Concrete Pier Cap		Length (ft.)																			
234	Reinforced Concrete Pier Cap Reinforced Concrete Cap		Length (ft.)																			
235	Timber Pier Cap		Length (ft.)									3795.61										
236	Other Pier Cap		Length (ft.)																			

Figure 12 – Unit Cost Database (C).

EN	Description	Category	Unit	Element construction cost in $																		
				2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
240	Steel Culvert																					
241	Reinforced Concrete Culvert																					
243	Other Culvert	**Culverts**	**Length (ft.)**																			
244	Masonry Culvert																					
245	Prestressed Concrete Culvert														7500.00							
300	Strip Seal Expansion Joint						106.00				150.00	150.00						350.00			250.00	
301	Pourable Joint Seal											293.50										
302	Compression Joint Seal																					
303	Assemble Joint with Seal	**Joints**	**Length (ft.)**																			
304	Open Expansion Joint																					
305	Assemble Joint without Seal																					
306	Other Joint																					
310	Elastomeric Bearing											6451.10										
311	Movable Bearing																					
312	Enclosed/Concealed Bearing																					
313	Fixed Bearing	**Bearings**	**Each**	2000.00																		
314	Pot Bearing														57608.50	100100.35		35000.00				
315	Disk Bearing (disc)																					
316	Other Bearing																					
330	Metal Bridge Railing																					
331	Reinforced Concrete Bridge Railing																					
	Concrete Bridge railing											786.98										
332	Timber Bridge Railing																					
333	Other Bridge Railing	**Railings**	**Length (ft.)**									671.46										
334	Masonry Bridge Railing																					
	Steel Guardrail																					
	1. T Beam													122.64	59.28	60.55	62.99	72.97	72.59	72.06	78.95	
	2. W Beam													15.39	16.83	19.30	16.96	25.23	18.77	21.71	24.55	
510	Wearing Surfaces	**Wearing Surf.**																				
515	Steel Protective Coatings	**Protective**	**Area (sq. ft.)**																			
521	Concrete Protective Coatings	**Coat. etc.**																				

Figure 12 – Unit Cost Database (D).

To begin filling in cells in the created database, research was performed on neighboring Department of Transportations' unit costs. Many DOT's had publically published data detailing the price of necessary elements over the years, such as FDOT and TDOT. GDOT also provided the research team with maintenance and new bridge project data in the form of line item costs, which were then able to be matched up with elements in the database, shown in Figure 13. Provided GDOT information is further described in Section 2.1.2.

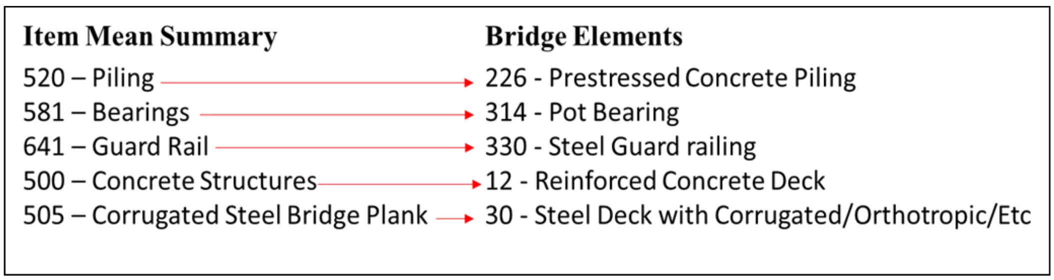

Figure 13 - Matching Item Mean Summary to Bridge Elements.

2.1.2 *Cost of Bridge Elements from GDOT Construction and Bidding*

GDOT's construction bidding division was able to provide the research team with maintenance project information, new bridge project information, as well as the line items, quantities, unit costs, and identification information for the projects. There were two files provided, one contained new and maintenance bridge project numbers, specific to GDOT, as well as unit cost data corresponding to those bridges. The cost data provided was unit prices for specific GDOT line item codes referenced within Georgia's specifications manual. There was also additional information on the county, vendor, contract, and letting date within the document. The second excel file contained bridge project numbers specific to GDOT, along with the more well used Bridge ID number referenced in the NBI database. This file also contained additional data on structure improvement length, and FHWA element identifications. Data from both of these files was able to be combined to match up the GDOT specific bridge identification with the NBI identification for the same bridges. Data was combined by coordinating GDOT specific bridge ID's in the first excel file to the second excel file. This was possible by using an excel lookup function that used bridge ID's from the first excel file to pick out data in the second file the user defined. The information defined to be extracted from the second excel file, using bridge ID's from the first file, was GDOT specific bridge ID's, NBI bridge ID's, and the unit cost information corresponding to the bride ID's. Therefore, data from both excel files received by GDOT's construction bidding team was able to be combined using the documents common GDOT bridge ID.

For some bridge maintenance projects, multiple bridges were associated with a single project number. Thus, the assumption was made that the total project cost was divided among each single bridge cost equally, until more provided information would prove otherwise. Line item unit costs from the provided documents were verified with GDOT's specification manual and coordinated with the corresponding bridge elements in the cost database. These values were then highlighted blue to keep track of where they came from, i.e., GDOT.

2.1.3 *Literature Review*

Once information from provided GDOT files was exhausted, more research was done on neighboring Department of Transportations. Figures associated with element unit costs were collected from Tennessee, and Florida's publicly discovered cost information. Florida has a Bridge Development Report (BDR) published over multiple years that lists their unit costs for bridge elements. Tennessee also has public data from 2000 to 2017 on their reported unit cost data.

Unit cost figures were able to be identified for multiple years through Florida's published BDR cost estimate, which informs their engineers on unit prices of specific elements within the superstructure, substructure, or deck. The information is used for replacement and new bridge construction cost estimates. Florida also published a document where they displayed previous unit costs in their AASHTO manual adaptation report. The unit costs were for replacement costs of a few specific bridge elements. From Florida information on steel box girder, steel truss, steel pile, prestressed concrete pile, and strip seal expansion joint was found and recorded in the database. Tennessee's Department of Transportation had publicly available files on average element bid prices for a multitude of years, easily found on their DOT website. These values were from actual construction projects within the state and all aggregated in a report corresponding to the year in which they took place.

When searching for more unit cost data from sates other than Georgia, it was necessary to stay as close in the South Eastern region of the United States as possible. From this region the most accurate set of data will be able to be discovered, assuming Southern states experience similar cost trends cost over the years. From the collected element cost information within the database a trend analysis will be able to be performed on elements with unit costs for consecutive years. These unit costs will be able to be used to predict future costs in 2018 and beyond. This process is further described in Section 3.1 of the preliminary analysis results.

Finally, a summary table was generated to provide the minimum and maximum price of bridge elements and will be presented in Section 3.1 as well.

2.2 Conjoint Analysis

A bridge's health index is a numbered valuation of its condition based upon factors observed during bridge inspections. The health index assists engineers in determining the structures overall condition, as well as helps when making decisions about maintenance or replacement. However, there is concern that the health index does not take into account environmental and indirect factors that will not be able to be represented in inspections and consequently in the health index. Attributes such as location and age are not best indicated in health index scores. Therefore, a conjoint analysis will assist in creating a system to apply the, above mentioned attributes, to the health index. The Modified health index (MHI_{BR}) of each bridge is an aggregated measure of it elements' health indexes (HI_e). Therefore, the factors (or attributes) must be applied at an element level.

A conjoint analysis was conducted to evaluate attribute-worths and weighting factors for the element health index, as corrective factors. A conjoint analysis is a type of survey (or a regression analysis) that is able to measure preferences and trade-offs respondents are willing to make by asking leading questions about defined attributes. Trade-offs, signify what an individual is willing to sacrifice for an aspect they view as important. The conjoint analysis will be able to determine what combination of attributes respondents value most highly or most detrimental to bridge health. These observations are able to be turned into attribute-worths, a numbered representation of preferences and trade-offs. Subsequently, the attribute-worths were used to determine scaling factors to be applied to an element health index and Georgia's bridge health index.

The process of designing the conjoint analysis, to develop attribute-worths, required five fundamental phases:

- Select attributes and levels
- Determine preferences between attributes (x values)
- Recode the numbered rank (y variables)
- Use regression to solve for β coefficients
- Use x, y, and β variables to solve for attribute-worths and total scores

2.2.1 *Design of Conjoint Analysis*

To start designing a conjoint analysis, attributes that most affect the bridge needed to be determined. For the bridge deck element, three factors were determined and expanded upon: construction year, geographic location, and presence of waterway. Older bridges are prone to deterioration in comparison to newer bridges; thus, the age as an attribute was deemed important to include. Based upon depreciation curves for bridges in different regions of Georgia, location had an influence on health. Thus, bridges were examined to determine if there was a correlation between region and bridge health. Geographic location was included because bridges in colder regions, or regions with extreme weather conditions, appeared to deteriorate faster than those in "normal" weather conditions such as the Central region. Furthermore, it is well known that water may cause early aging to bridge elements due to corrosion and faster deterioration, accordingly presence of waterway was determined to be an important factor to consider.

For example, an old bridge deck element located in North Georgia and crossing a waterway has an element health score of 70. Another relatively newer non-waterway bridge located in the Central Georgia has a health score of 70. Generally, the two health indexes are considered to provide an equal weight on determining the overall bridge condition. However, a permutation of the attribute-worths determines bridges' depreciation rate and thus a combined-worth of attributes.

The attribute-worth will be able to consider the location, age, presence of waterway and provide a more accurate health score by taking into account the attributes. The following quantitative and qualitative attributes are selected:

- **Attributes:** Construction Year, Geographic Region, Presence of Waterway
- **Levels:** Construction Year - Year < 2020, Year < 2000, Year < 1980

  Geographic Region - Northern, Central, Southern

  Waterway - Waterway, Non-waterway

Levels were initially ranked based on importance of attributes. This process will generally be completed by conducting a survey with stakeholders, such as the GDOT's Bridge Maintenance Unit, and a review of available literature. Preferences were categorized on a scale of one to eighteen, because of the eighteen possible combinations (3 x 3 x 2 = 18). Rank eighteen was considered to be the most vulnerable combination of attributes and most detrimental to bridge deck health, while rank one was determined to be the least concerning to a bridge's health. For each rank an individual will chose one level from each attribute. Starting from rank 18 and moving upwards to rank 1 an individual will mark the levels considered most harmful to the bridge. This process is shown in Table 10.

The attribute year, region, and waterway were selected based upon Georgia's bridge condition ratings. When studying the condition ratings for bridge deck, superstructure, and substructure it was observed these attributes were seen to most negatively affect the health of the bridge. Ranks were also observed from condition rating observations. Such as when analyzing the deck, it was noticed bridge health deteriorated faster in the North. Therefore these observations were reflected in the preferences chosen in Table 10. For the bridge Substructure and Superstructure this observation of condition ratings and reflection into ranks is also done.

Table 10 - Attribute Preferences for Bridge Deck

YR < 2020 (x_1)	YR < 2000 (x_2)	YR < 1980 (x_3)	Northern (x_4)	Central (x_5)	Southern (x_6)	Waterway (x_7)	Non-Waterway (x_8)	Rank (y)
x				x			x	1
x					x		x	2
	x			x			x	3
	x				x		x	4
x			x				x	5
x				x		x		6
x					x	x		7
	x		x				x	8
x			x			x		9
	x			x		x		10
	x				x	x		11
		x		x			x	12
		x			x		x	13
	x		x			x		14
		x		x		x		15
		x	x				x	16
		x			x	x		17
		x	x			x		18

The design ranked 18 is considered to be the most concerning combination to a bridge deck's health. An old bridge in the Northern region of Georgia, with the possibility of sitting in a waterway will have the worst influence on a bridge's wellbeing. Rank 1 is considered to be the least concerning situation for a bridge deck. Because the bridge is newer (year less than 2020 but greater than 2000), in the Central region of Georgia, and not in a waterway. Trade-offs are seen in rank 14 where the possibility of the bridge being in a waterway, in the North, and in newer condition was chosen as more vulnerable than rank 13. Where rank 13 is an older bridge but in a more favorable Southern region, and is non-waterway. For instance, this demonstrates that even if a bridge is older, it is not in a more vulnerable condition than one in bad weather and waterway circumstances.

after preferences are designated, attributes selected for each rank are tagged as one and attributes not selected are substituted with a zero, as seen in Table 11. Therefore, rank for 1 the selected levels, year less than 2020, Central, and non-waterway are tagged as one. While all other attribute levels not chosen for rank 1 are labeled zero. This binary approach was necessary to perform a regression analysis with qualitative variables such as geographic locations and presence of a waterway. Variable labels, x_1, $x_2 \ldots x_8$, are assigned to each attribute, and the rank is labeled as the 'y' variable.

Table 11 - Binary Attribute Preferences for Bridge Deck

YR < 2020 (x_1)	YR < 2000 (x_2)	YR < 1980 (x_3)	Northern (x_4)	Central (x_5)	Southern (x_6)	Waterway (x_7)	Non-Waterway (x_8)	Rank (y)
1	0	0	0	1	0	0	1	1
1	0	0	0	0	1	0	1	2
0	1	0	0	1	0	0	1	3
0	1	0	0	0	1	0	1	4
1	0	0	1	0	0	0	1	5
1	0	0	0	1	0	1	0	6
1	0	0	0	0	1	1	0	7
0	1	0	1	0	0	0	1	8
1	0	0	1	0	0	1	0	9
0	1	0	0	1	0	1	0	10
0	1	0	0	0	1	1	0	11
0	0	1	0	1	0	0	1	12
0	0	1	0	0	1	0	1	13
0	1	0	1	0	0	1	0	14
0	0	1	0	1	0	1	0	15
0	0	1	1	0	0	0	1	16
0	0	1	0	0	1	1	0	17
0	0	1	1	0	0	1	0	18
β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	

After the binary approach to ranking preferences, a regression analysis was used to further analyze the data. A regression analysis is a way to estimate relationships among variables. In this case a regression analysis will be able to define the β variables assigned to each attribute. Where the β variables represent attribute-worth:

- Year < 2020: β_1
- Year < 2000: β_2
- Year < 1980: β_3
- Northern: β_4
- Central: β_5
- Southern: β_6
- Waterway: β_7
- Non-waterway: β_8

However, the data must first be modified. In regression analysis, the independent variable must not be "perfectly predictable" based upon another independent variable or combinations of independent variables. This is because the regression analysis will not be able to separate the effects of the confounded variables (Amarchinta, 2007). To alleviate this issue, a row from each attribute category was removed, which is equivalent to assuming the beta variables missing in Eq. 9 are zero. Essentially, having information about two levels from the year and region, and one from waterway will give enough information about the removed rows based upon principles of linear dependency. The formula derived to solve for the bridge deck's score is as follows:

$$yl = \beta_0 + \beta_2 x_2 + \beta_3 x_3 + \beta_5 x_5 + \beta_6 x_6 + \beta_8 x_8 \quad \textbf{Eq. 9}$$

β_0 is the intercept

β's are the attribute-worths to be estimated, indicating preference

yl is the recoded ranking

The rank (y variable) needs to be recoded to yl to determine the best fitting model between dependent variables (outcomes) and independent variables (predictions). Fitting the binary zero and one x values to the outcome, y rankings, is not ideal. The recoding of the y value allows for a more linear relationship between x and y values. The equation to solve yl is the logarithm of the odds, where p is the probability. Results from the recoding are illustrated in Table 12.

$$\mathrm{p} = \frac{y - \min + 1}{\max - \min + 2} \qquad \textbf{Eq. 10}$$

p is the probability

y is the ranking

min and max are the minimum and maximum of the ranking values (y)

$$\text{Y recoding (yl)} = ln\frac{p}{1-p} \qquad \textbf{Eq. 11}$$

Table 12 - Recoding of y Values for Bridge Deck

Rank (y)	Recoding (yl)
1	-2.89
2	-2.14
3	-1.67
4	-1.32
5	-1.03
6	-0.77
7	-0.54
8	-0.32
9	-0.11
10	0.11
11	0.32
12	0.54
13	0.77
14	1.03
15	1.32
16	1.67
17	2.14
18	2.89

Once the new yl value is determined β variables are now able to be solved for. To solve for them it is necessary to conduct a regression analysis. Excel has a data analysis tool that preforms the regression analysis when inputs for x and y variables are specified. The x variables are the zero and one values from Table 11, excluding the first column from each attribute type. The y values used are calculated from the y recoding (yl). Once the variables are selected, excel created a summary output table with the values for the β coefficients.

Table 13 - Solved Coefficient Values for Bridge Deck

	Coefficients
β_0	0.18
β_2	0.84
β_3	2.71
β_5	-1.16
β_6	-0.82
β_8	-1.36

Regression is only able to define the β coefficients of columns that were not removed. Therefore, β_1 β_4 and β_7 are missing (or assumed zero) because these are the columns that were removed to be able to use the regression analysis technique successfully. To attain values for these missing β coefficients, a process in which the known coefficients are brought back to a positive scale and unknown coefficients are given a value of one by taking the exponent of coefficients is performed. The product of this process is used to find the attribute-worth by scaling the β coefficients by their attribute group. This process and the processes to determine total score, and attribute-worth scaling values to be applied to the element heath score are further explained in the results, Section 3.2.

2.3 Element Asset Valuation

2.3.1 *Modified Health Index*

A bridge's health index is representation of its condition, based upon factors observed during inspections. The health index value ranges from 0 to 100, with 0 indicating a bridge in bad condition. GDOT engineers value health indexes of 60 to70 as ideal and anything above in excellent condition. Bridges below 60 are usually considered to be in poor condition. Figure 14 shows the current condition of Georgia's bridges through a histogram of the heath indexes. A majority of bridges ae in excellent condition, above 80. A smaller mount is in good condition, range 60 to70. There is a spike in the number of bridges with a health index around 56, poor condition. These index values are one of the factors engineers use to decide when bridges need maintenance. However, there is concern that the health index does not take into account environmental and indirect factors that will not be able to be represented in inspections and consequently in the health index. Therefore the asset valuation, in conjunction with the conjoint analysis, will be able to alter health indexes into more accurate representations of bridge health.

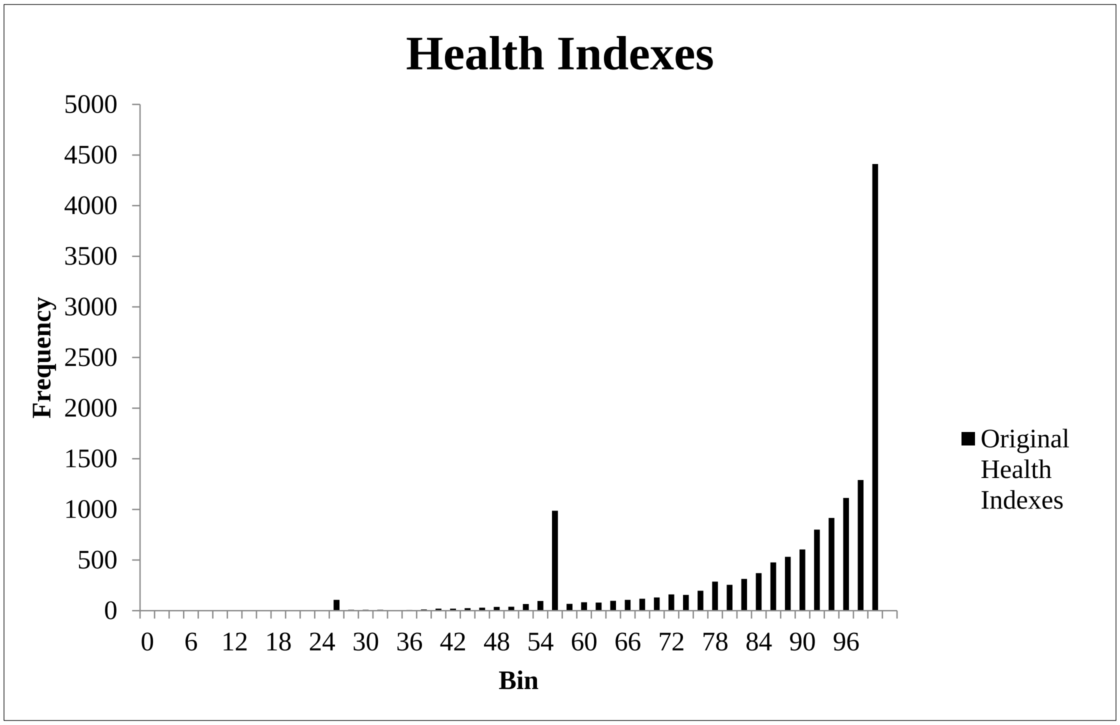

Figure 14 – Original Health Indexes Before Modification.

2.3.2 *Valuation of Bridge Asset Based on MHI*

Asset valuation will be performed by modifying the health indexes seen in the previous section. Using the Attribute-worth developed in Section 3.2 of the conjoint analysis results, the health index values will be modified to more correctly represent the actual health of the bridge. The attribute-worths will be applied to the health index values by bridge component: deck, superstructure, and substructure.

2.4 Cash Flow Analysis

A cash flow analysis will help Georgia Department of Transportation engineer's better track the condition of their bridges. Cost data is available on bridge maintenance through the National Bridge Inventory database (NBI) that tracks bridge total cost and repair costs from 1992 to the current year. GDOT cost data deciphered when developing the element cost database is also available to use in the analysis tool. GDOT’s data includes maintenance project information, new bridge project information, as well as the line items, quantities, unit costs, and identification information for the projects. NBI and GDOT are two separate data entities, therefore their information is not combined. Because of this issue it is difficult for Georgia to understand the full picture of their bridges’ health and the amount of money being allotted towards the infrastructure. The created cash flow analysis tool solves this problem by combining all of the available data within one excel sheet, and creating a process to easily access the information. The analysis tool uses excel ‘macros’ to automate the process of requesting cost data from a particular bridge. It goes further to provide a visual representation of the money allocated to a specific bridge asset, as to better understand the values presented. The cash flow analysis tool evidence on the impacts of regular maintenance of infrastructure, and warning guide to overspending on bridges.

Data for the cash flow analysis was collected from the NBI database, dating back to 1992, as well as maintenance line item unit costs provided by GDOT’s construction bidding office, dating back to 2011. The NBI database is multiple text files with bridge data for a corresponding year. The text files can be opened in excel, to better sort and cache the information for what is necessary to the project. Extracted from the NBI database was the total improvement cost, the year of that improvement cost, and the year the bridge was created for each bridge from 1992 to 2017. The total improvement cost is the total cost of maintenance on the bridge, including roadway and bridge improvement costs. The data was extracted from NBI excel files by using an excel lookup formula that obtained the total improvement cost when a bridge ID was provided. Specific data taken from GDOT originated from files combined during the collection of element costs, Section 2.1. Values extracted were the total maintenance cost of bridge projects from the years 2011 to 2018.

The data from both sources was combined into a single excel tab, of the cash flow analysis excel sheet, for each maintenance bridge ID provided by GDOT. Data gathered, such as interest rate, modified health index, and year of initial construction was established for each bridge ID as well. The interest rate was needed when the net present value of expenses was later calculated, and the modified health index was necessary when the benefit of a bridge structure was calculated. Costs collected from the NBI database every year were assumed to be the reoccurring maintenance costs, from reading the cost description in the NBI handbook. All of the cost values were also calculated as Net Present Value (NPV). The NPV was calculated individually for each maintenance expense of every bridge project, so a user of the cash flow analysis tool is able to understand the present value of the past expenses. The NPV was also conducted for the entirety of each bridge project. Meaning, a single NPV value was produced after taking into account the historical cost and maintenance expenses through a bridge's lifetime. NPV was calculated using the excel net present value function. The function only requires the interest rate and any expenses the user wishes to bring from past to a present value, such as maintenance expenses.

All of the data collected, gathered, and organized was used as a reference, general data to be used when computing the cash flow and the physical cash flow diagram. Excel macros were used to automate the process of locating all of the cost information for one particular bridge and producing the chart of a bridge's cash flow analysis. A macro is a coding technique that records mouse clicks deliberately made, so as to repeat them for a different set of numbers when the macro is assigned to a specific function, such as a button. The process for a user to see the cash flow analysis of a particular bridge ID is as follows:

- Select or type a bridge ID (NBI bridge ID) from the drop down menu
- Select the "Make Chart" button

- The "Make Chart" button will first produce a table displaying historical cost, maintenance expenses, NPV, and benefit
- The "Make Chart" button will also bring the user to a bar chart that visually expresses the costs and benefits throughout the selected bridges lifetime

The first macro, a drop down menu, was created so the user could search through, or type in, a bridge ID they would like data on. Another macro was created, in the form of a button to generate all of the cost data for the bridge selected from the drop down menu. This button was labeled the "Make Chart" button, as seen in Figure 16. Once the user presses the "Make Chart" button the macro will automatically generate a list of NBI and GDOT cost information, with the corresponding years, as well as the NPV of each of those values, which is displayed in Table 14. Pressing the "Make Chart" button also generates the current benefit of the bridge. The benefit of a bridge is the bridge's current equity. It is a way to monetarily value the bridge based upon its historical cost and health index. It works to contrast the expenses or costs a bridge incurs. The bridge benefit is calculated by taking into account the modified health index of the bridge:

$$\text{Benefit Equation} = (\text{Health Index}/100)*\text{Initial Project Cost} \qquad \textbf{Eq. 12}$$

The last function the button does is bring the user to a new excel tab where the cash flow chart appears. The chart displays all of the money invested in the bridge as negative, red, and the current benefit of the structure as positive, green. This chart is shown in Figure 15.

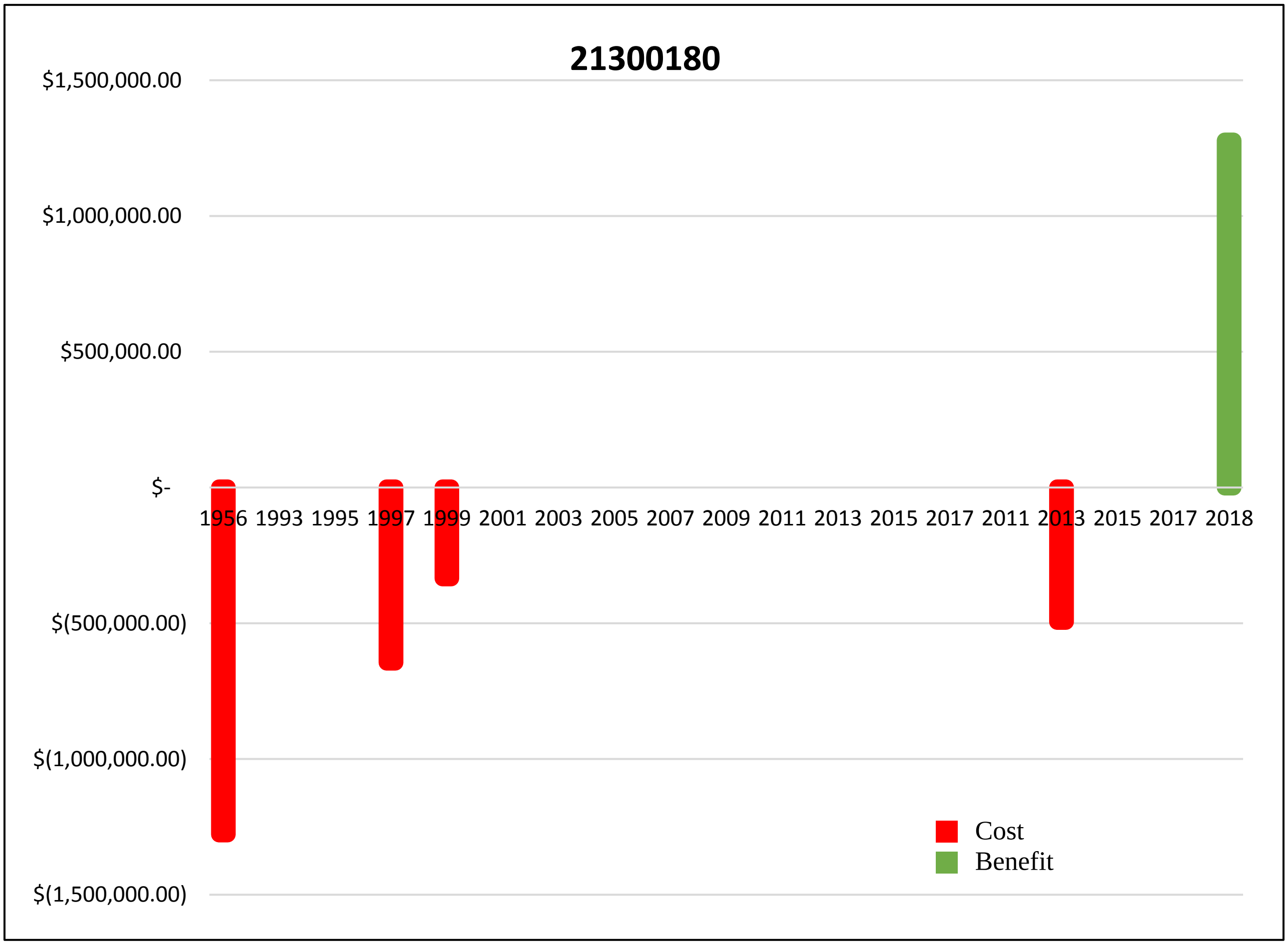

Figure 15 **- Example of Cash Flow Chart for Georgia Bridge ID 21300180.**

Table 14 - Example of Input data generated for Georgia Bridge 21300180

	Year	Expenses	NPV Expenses	Interest Rate	Total NPV
Historic Cost	1956	$ (1,278,000.00)	$ (1,278,000.00)	0.03	($1,505,615.62)
NBI	1992	$ -	$ -		
	1993	$ -	$ -		
	1994	$ -	$ -		
	1995	$ -	$ -		
	1996	$ -	$ -		
	1997	$ (645,000.00)	$ (191,970.06)		
	1998	$ -	$ -		
	1999	$ (335,000.00)	$ (93,981.88)		
	2000	$ -	$ -		
	2001	$ -	$ -		
	2002	$ -	$ -		
	2003	$ -	$ -		
	2004	$ -	$ -		
	2005	$ -	$ -		
	2006	$ -	$ -		
	2007	$ -	$ -		
	2008	$ -	$ -		
	2009	$ -	$ -		
	2010	$ -	$ -		
	2011	$ -	$ -		
	2012	$ -	$ -		
	2013	$ -	$ -		
	2014	$ -	$ -		
	2015	$ -	$ -		
	2016	$ -	$ -		
	2017	$ -	$ -		
	2018	$ -	$ -		
GDOT	2011	$ -	$ -		
	2012	$ -	$ -		
	2013	$ (494,975.00)	$ (91,803.97)		
	2014	$ -	$ -		
	2015	$ -	$ -		
	2016	$ -	$ -		
	2017	$ -	$ -		
	2018	$ -	$ -		
Benefit	2018	$ 1,278,000.00	$ 1,278,000.00		

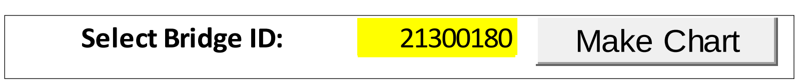

Figure 16 – Drop Down Menu and Make Chart Button.

To compare and contrast the equity of two separate bridges, the cash flow analysis tool allows the user to also evaluate two bridges at the same time. Another excel tab performs the same functions as the first cash flow tab, but as a comparison of two bridges. It repeats the process of gathering data and displaying a bar chart for two bridges instead of one. In the bar graph both bridge expenses are in the same chart to better compare. The user is prompted to select two bridge ID's from the two separate drop down menus, then select the "Make Chart" button to receive cash flow information. The results from this process are shown in Table 15. The process lays out bridge cost data in side by side quantitative tables and displays the cost and benefit of the two selected bridges wanted to compare on the same cash flow chart, as seen in Figure 17.

Table 15 – Bridge Comparison of 21300180 and 12104760

	Year	Expenses	NPV Expenses
Historic Cost	1956	$ (1,278,000.00)	$ (1,278,000.00)
NBI	1992	$ -	$ -
	1993	$ -	$ -
	1994	$ -	$ -
	1995	$ -	$ -
	1996	$ -	$ -
	1997	$ (645,000.00)	$ (191,970.06)
	1998	$ -	$ -
	1999	$ (335,000.00)	$ (93,981.88)
	2000	$ -	$ -
	2001	$ -	$ -
	2002	$ -	$ -
	2003	$ -	$ -
	2004	$ -	$ -
	2005	$ -	$ -
	2006	$ -	$ -
	2007	$ -	$ -
	2008	$ -	$ -
	2009	$ -	$ -
	2010	$ -	$ -
	2011	$ -	$ -
	2012	$ -	$ -
	2013	$ -	$ -
	2014	$ -	$ -
	2015	$ -	$ -
	2016	$ -	$ -
	2017	$ -	$ -
	2018	$ -	$ -
GDOT	2011	$ -	$ -
	2012	$ -	$ -
	2013	$ (494,975.00)	$ (91,803.97)
	2014	$ -	$ -
	2015	$ -	$ -
	2016	$ -	$ -
	2017	$ -	$ -
	2018	$ -	$ -
Benefit	2018	$ 1,278,000.00	$ 1,278,000.00

	Year	Expenses	NPV Expenses
Historic Cost	1968	$ (1,383,000.00)	$ (1,383,000.00)
NBI	1992	$ -	$ -
	1993	$ -	$ -
	1994	$ -	$ -
	1995	$ -	$ -
	1996	$ -	$ -
	1997	$ (813,000.00)	$ (344,993.59)
	1998	$ -	$ -
	1999	$ -	$ -
	2000	$ -	$ -
	2001	$ -	$ -
	2002	$ -	$ -
	2003	$ -	$ -
	2004	$ -	$ -
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	2014	$ -	$ -
	2015	$ -	$ -
	2016	$ -	$ -
	2017	$ -	$ -
	2018	$ -	$ -
GDOT	2011	$ -	$ -
	2012	$ -	$ -
	2013	$ -	$ -
	2014	$ -	$ -
	2015	$ -	$ -
	2016	$ (184,308.00)	$ -
	2017	$ -	$ -
	2018	$ -	$ -
Benefit	2018	$ 972,110.70	$ 972,110.70

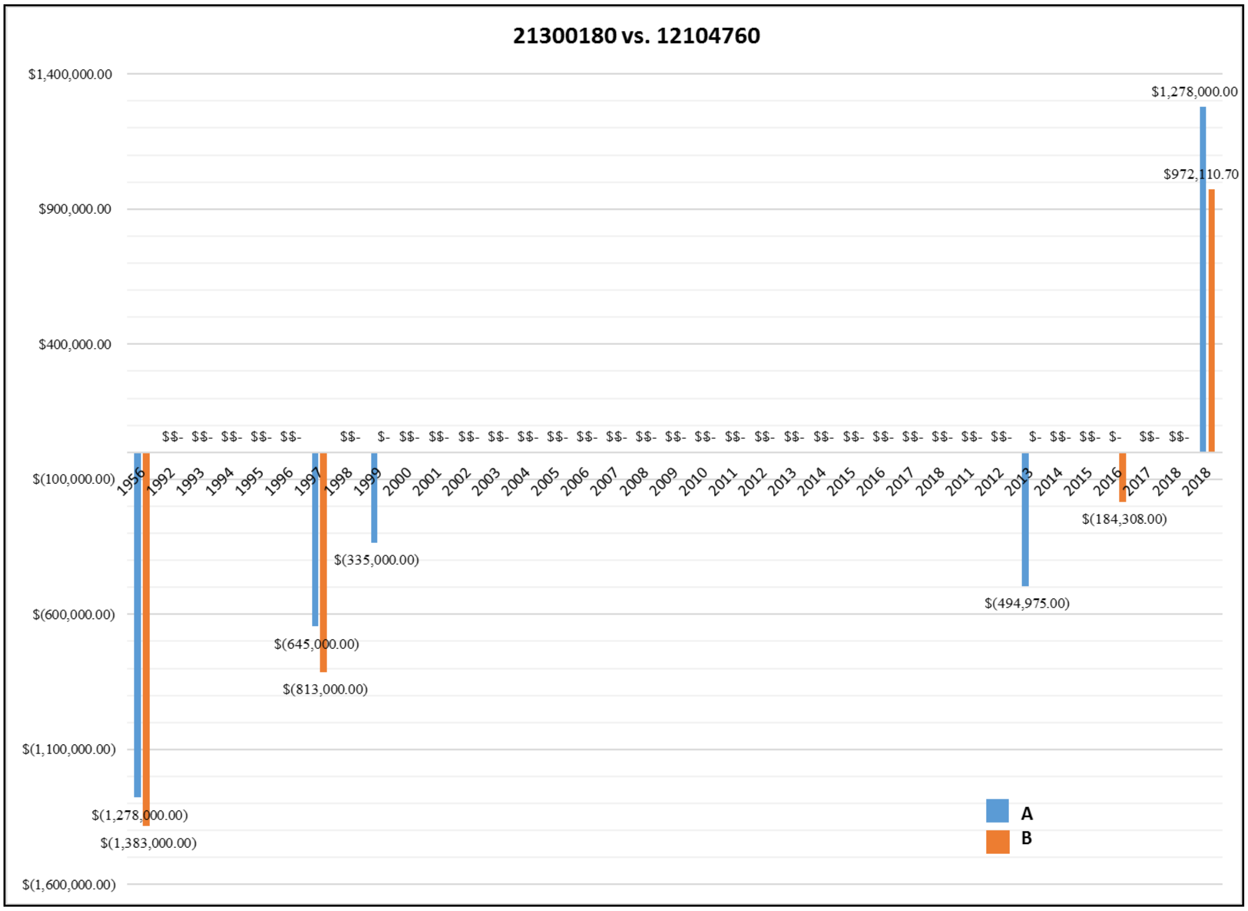

Figure 17 - Example of Cash Flow Chart Comparison.

2.5 Discussion and Summary

The goal of collecting element costs was to set up a base for the unit cost database. To start the element unit cost database, first sources needed to be determined to then be applied. It was necessary to find reputable and applicable sources to start growing the database. Similarly, to be able to attain attribute-worths it was necessary to first determine preferences. The preferences will be the basis for determining values to be applied to the health indexes. Therefore, perfecting preferences is an important step. The asset valuation sets up the basis for the cash flow analysis by gathering data and collecting all necessary elements to create an analysis tool. Collecting the best data and sorting data is important to creating tools that will be able to be useable and produce accurate results. GDOT was able to provide much of the data used, thus sorting it out was necessary for much of the methodology process.

3. CONJOINT ANALYSIS RESULTS

3.1 Conjoint Analysis Development

This section describes how the attribute-worths are determined from Section 2.2 of the methodology. Once attribute-worths are determined, they are used to find the total score of all preferences. The total score is then used to create the rescaled attribute-worths that will be applied to bridge element health index as a modification factor. To obtain the modification factors the following steps must first occur:

1. Solve for missing (zero) β variables;
2. Determine the total score using all β and x variables;
3. Rescale the total score into a rescaled attribute worth to be applied to the health index; and
4. Apply rescaled attribute worth, adjust results, and analyze outcomes.

A box and whisker diagram of the residual plot from the regression analysis is presented in Figure 18 for YR< 2000, YR< 1980, Northern, Southern, and Waterway attributes. A residual plot measures how data points, zero and one values of attributes, match the regression line. The box and whisker diagram in Figure 18 displays the shape of the distribution. To further analyze the point data, Table 16 was created to list the minimum and maximum values for each attribute's zero and one value. This data displays small residual values, as well as some continuity between the different attributes. Indicating the correlation between the zero or one values, and the 'yl' rank values is high. The R-squared value of the regression, 0.98, also measures how well the data is fitted to a regression line which is characterized by the beta coefficients in this study. For a regression analysis which involves qualitative variables, such a R-squared value is considered very high.

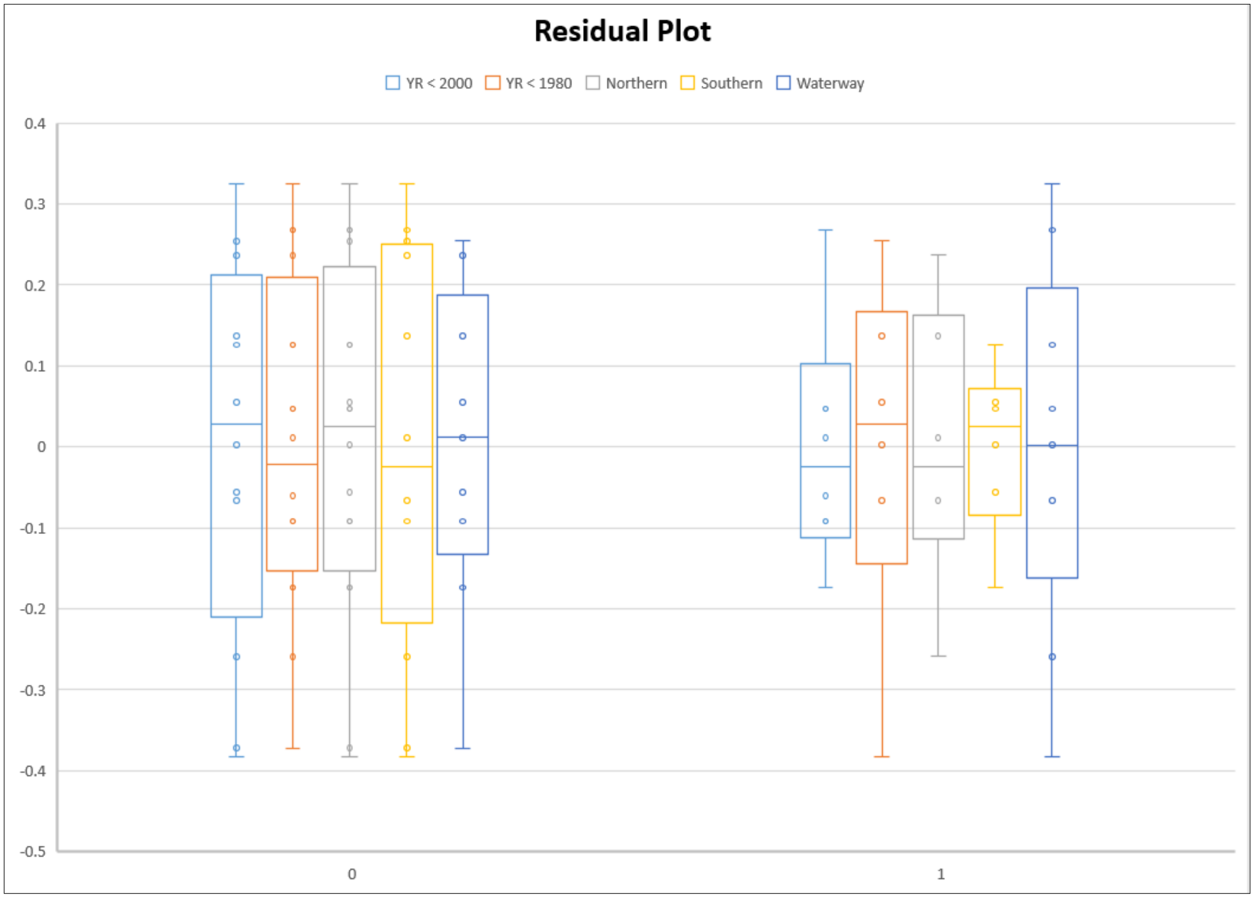

Figure 18 – Box and Whisker Diagram of Residual plots.

Table 16 – Residual values of attributes

Residual Values	0		1	
	Min	Max	Min	Max
YR < 2000 (x2)	-0.37	0.33	-0.17	0.27
YR < 1980 (x3)	-0.37	0.33	-0.38	0.25
Southern (x6)	-0.38	0.33	-0.17	0.13
Northern (x4)	-0.37	0.33	-0.26	0.24
Waterway (x7)	-0.37	0.24	-0.38	0.33

To determine attribute-worth, β coefficients are used. A process in which the known coefficients are brought back to a positive scale and unknown coefficients are given a value of one by taking the exponent of coefficients is performed. First, the exponent of all of the coefficient values are taken. For β coefficients that were not removed during the ranking of preferences process (known β's) the exponent is taken of the value. For β coefficients that were removed to perform the regression analysis in Section 2.2 (unknown β's), the coefficient is taken of zero because they did not receive a value from regression. To find the attribute-worth for the bridge deck element, β values were grouped together by their attribute group and summed. Subsequently, each β exponent value is divided by the sum of the attribute group. Equation 15 shows this process for β_1 of the construction year attribute group. The outcomes of this process are shown in Table 17.

$$\text{Known } \beta = \exp(\beta \text{ coefficient}) \qquad \textbf{Eq. 13}$$

$$\text{Unknown } \beta = \exp(0) \qquad \textbf{Eq. 14}$$

$$\beta_1 \text{ Attribute Worth} = \frac{\exp(\beta_1)}{((\exp(\beta_1)+\exp(\beta_2)+\exp(\beta_3)))} \qquad \textbf{Eq. 15}$$

Table 17 - Attribute-Worth for Bridge Deck

	Coefficient	**Exponent**	**Attribute-Worth**
β_0	0.18		
$\boldsymbol{\beta_1}$	0.00	1.00	0.05
$\boldsymbol{\beta_2}$	0.84	2.32	0.13
$\boldsymbol{\beta_3}$	2.71	15.02	0.82
	Sum >	18.35	
β_4	0.00	1.00	0.57
β_5	-1.16	0.31	0.18
β_6	-0.82	0.44	0.25
	Sum >	1.76	
$\boldsymbol{\beta_7}$	0.00	1.00	0.80
$\boldsymbol{\beta_8}$	-1.36	0.26	0.20
	Sum >	1.26	

A total score (for a permutation of attributes) is to be determined for each rank using β attribute-worths found in Table 17 and x values in Table 18. The total score represents a numerical value that describes the preference of each rank, displayed in Table 18. Where the x values are the zero and one values in each row for every rank. β values are the percentages of their attribute-worth. To calculate the total score, in excel the β values for each attribute level are multiplied by the corresponding x value for the attribute level (zero or one). The process is repeated until the last level is reached and these values are then summed together to obtain the total score.

$$\text{Total Score} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 \quad \textbf{Eq. 16}$$

Rank 18: 2.18 = (5x0)+(13x0)+(82x1)+(57x1)+(18x0)+(25x0)+(80x1)+(20x0)

Table 18 - Total Scores for Bridge Deck

YR < 2020 (x_1)	YR < 2000 (x_2)	YR < 1980 (x_3)	Northern (x_4)	Central (x_5)	Southern (x_6)	Waterway (x_7)	Non-Waterway (x_8)	Total Score (y)
1	0	0	0	1	0	0	1	0.44
1	0	0	0	0	1	0	1	0.51
0	1	0	0	1	0	0	1	0.51
0	1	0	0	0	1	0	1	0.58
1	0	0	1	0	0	0	1	0.83
1	0	0	0	1	0	1	0	1.03
1	0	0	0	0	1	1	0	1.10
0	1	0	1	0	0	0	1	0.90
1	0	0	1	0	0	1	0	1.42
0	1	0	0	1	0	1	0	1.10
0	1	0	0	0	1	1	0	1.17
0	0	1	0	1	0	0	1	1.20
0	0	1	0	0	1	0	1	1.27
0	1	0	1	0	0	1	0	1.49
0	0	1	0	1	0	1	0	1.79
0	0	1	1	0	0	0	1	1.59
0	0	1	0	0	1	1	0	1.87
0	0	1	1	0	0	1	0	2.18

3.1.1 *Rescaling Attribute-Worth Values*

Once the conjoint analysis was completed by determining the total score, the scores were rescaled to be applied to the bridge health index. The rescaled total scores were identified as the rescaled attribute-worths. The total score needs to be rescaled because if applied as is to health scores the impact would be too dramatic, and adjust the health index scores more than necessary. To acquire these rescaled attribute worth values, for each rank, the total score was divided the total score for rank 12, to bring the scores down to an applicable value, shown in Table 19. The scaled value will have a less drastic and thus more realistic impact than the total score would, if applied to the element health indexes.

Table 19 – Rescaled Combined Attribute-Worths for Bridge Deck

YR < 2020 (x_1)	YR < 2000 (x_2)	YR < 1980 (x_3)	Northern (x_4)	Central (x5)	Southern (x_6)	Waterway (x_7)	Non-Waterway (x_8)	Rank (y)	Total Score	Rescaled Combined Attribute Worth
1	0	0	0	1	0	0	1	1	0.44	0.36
1	0	0	0	0	1	0	1	2	0.51	0.42
0	1	0	0	1	0	0	1	3	0.51	0.42
0	1	0	0	0	1	0	1	4	0.58	0.48
1	0	0	1	0	0	0	1	5	0.83	0.69
1	0	0	0	1	0	1	0	6	1.03	0.86
1	0	0	0	0	1	1	0	7	1.1	0.92
0	1	0	1	0	0	0	1	8	0.9	0.75
1	0	0	1	0	0	1	0	9	1.42	1.18
0	1	0	0	1	0	1	0	10	1.1	0.92
0	1	0	0	0	1	1	0	11	1.17	0.98
0	0	1	0	1	0	0	1	12	1.2	1.00
0	0	1	0	0	1	0	1	13	1.27	1.06
0	1	0	1	0	0	1	0	14	1.49	1.24
0	0	1	0	1	0	1	0	15	1.79	1.49
0	0	1	1	0	0	0	1	16	1.59	1.33
0	0	1	0	0	1	1	0	17	1.87	1.55
0	0	1	1	0	0	1	0	18	2.18	1.82

The rescaled attribute-worths were applied to Georgia's bridge element health index values through a Matlab code. The Matlab code was designed to compute the health index for bridge ID's and was modified to tag (attribute) variables in order to identify which rescaled attribute-worth would be applied to a bridge based upon the levels defined for each ranking.

For bridge ID's with a deck, a rescaled attribute-worth was applied to each element health index to develop the ConjointHI value. When the ConjointHI values exceed a score of 100, the values were used to scale all final adjusted health index values back to maximum of 100. The resulting quantities were defined as the Adjusted ConjointHI values. To achieve the Adjusted ConjointHI, each ConjointHI was divided by the largest ConjointHI. The process is displayed in Table 20.

Table 20 – Example of Applied Attribute Worth Results for Bridge Deck

Bridge ID	HI	ConjointHI	Adjusted ConjointHI
12105430	100.00	155.16	85.42
2101220	96.69	94.36	51.95
23750450	100.00	42.46	23.38
7300400	86.186	36.60	20.15
12101780	100.00	155.17	85.42
12104440	99.80	97.41	53.62
12101120	55.00	50.38	27.73
13950370	99.11	90.79	49.98
3300380	53.55	49.05	27.00

The results of this application are exhibited in a Histogram. Figure 19 expresses the distribution of bridge deck element health indexes before they were adjusted by the rescaled attribute worth values. This group of health indexes is a subset of all health index values, of bridges that contain a deck element. Most bridges, 3899 of them, have a health index ranging from 95 to

100. There was also a larger number of bridges, 656, with a health index ranging from 50 to 55. The remainder of bridges were generally distributed through ranges 35 to 90. Once rescaled attribute-worths were applied to the deck element health index, the ranges distribute more across all possible index values. Illustrated in Figure 20, there were peaks for health index ranges 20 to 25, 40 to 50, 50 to 55, and 80 to 85. The rescaled attribute-worths alter the health index factors so that they will take into account influences not included in the health index calculation. Because of the rescaling of the original health index values most bridges are rated at 50 or below. Indicating that the rescaled factors may need to be adjusted to lessen the correction impact to a more reasonable modification.

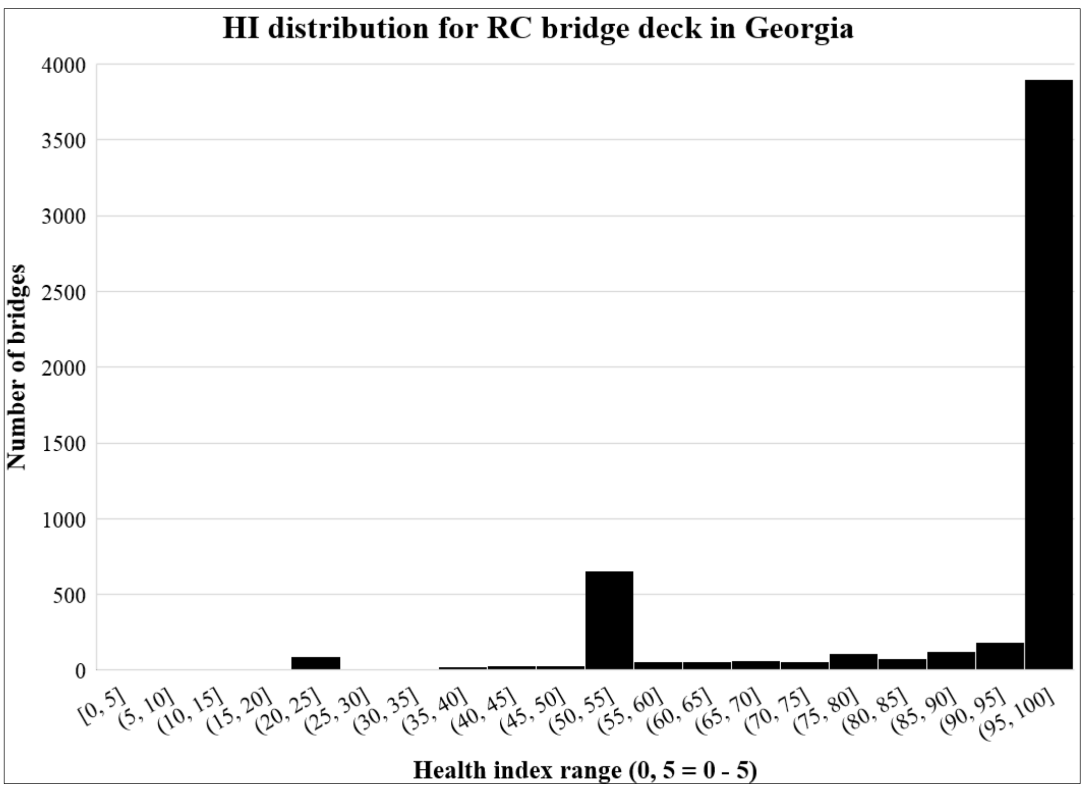

Figure 19 – Original Bridge Deck Element Health Index Ranges.

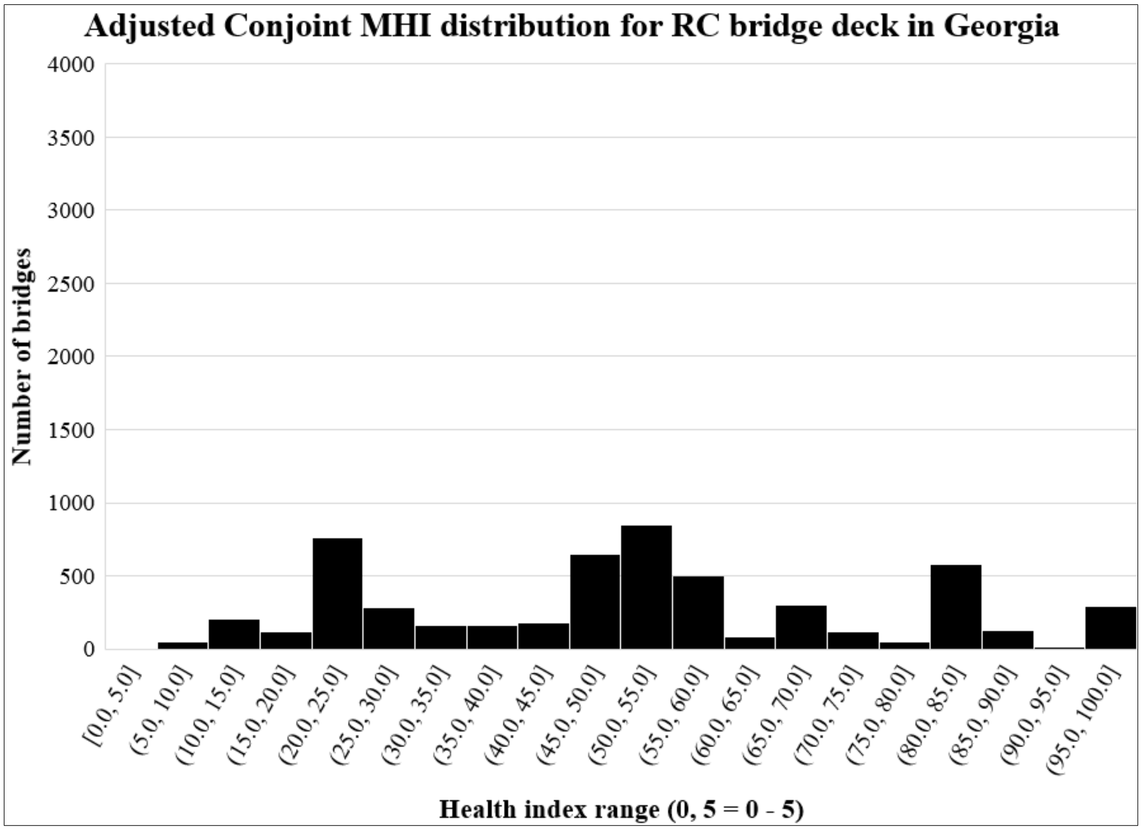

Figure 20 – **Adjusted Bridge Deck Element Health Index Ranges.**

When analyzing the results, it was determined that there is too much variation from the histogram of original HI's. The attribute-worth value should not alter the health index drastically, only enough to perform corrections. Therefore, another approach was taken to apply the attribute-worths to the health index values. This new method would stop the rapid variation occurring with the Adjusted ConjointHI's. It is believed the rescaled attribute-worths can be scaled so as not to exceed 1, rendering no use of the AdjustedHI. Because no ConjointHI value will exceed 100. This will stop the rapid variation shown in the Figure 20 and provide the best correction to the health index.

3.1.2 *Best Method to Apply Attribute-Worths to Health Indexes*

A new equation and set of attribute-worths was proposed to better alter the element health index values. The health index value, after being multiplied by the attribute-worth factors should not be altered more than 10 percent. This will be able to account for corrections to the health index, while not over adjusting the ConjointHI values drastically. To do this, ConjointHI will be calculated by the following equation.

$$\text{ConjointHI} = \text{Bridge Health Index} - 10 \times \text{Attribute-Worth} \qquad \textbf{Eq. 17}$$

The new attribute-worths, to be used with the previous equation, are displayed in Table 21. The new values for each attribute-worth are calculated by first taking the total score for a specific rank subtracting it by the total score for rank 1 (0.44) and dividing it by 1.74, the attribute-worth of rank 18. This method keeps all attribute-worths within a range of zero to one. When they are applied to bridge health index, using equation 17, they will only alter the health index value by a maximum of 10 points.

Table 21 – New Attribute-Worth Values for Bridge Deck

YR < 2020 (x_1)	YR < 2000 (x_2)	YR < 1980 (x_3)	Northern (x_4)	Central (x5)	Southern (x_6)	Waterway (x_7)	Non-Waterway (x_8)	Rank (y)	Total Score	Attribute - Worth
1	0	0	0	1	0	0	1	1	0.44	0.00
1	0	0	0	0	1	0	1	2	0.51	0.04
0	1	0	0	1	0	0	1	3	0.51	0.04
0	1	0	0	0	1	0	1	4	0.58	0.08
1	0	0	1	0	0	0	1	5	0.83	0.22
1	0	0	0	1	0	1	0	6	1.03	0.34
1	0	0	0	0	1	1	0	7	1.1	0.38
0	1	0	1	0	0	0	1	8	0.9	0.26
1	0	0	1	0	0	1	0	9	1.42	0.56
0	1	0	0	1	0	1	0	10	1.1	0.38
0	1	0	0	0	1	1	0	11	1.17	0.42
0	0	1	0	1	0	0	1	12	1.2	0.44
0	0	1	0	0	1	0	1	13	1.27	0.48
0	1	0	1	0	0	1	0	14	1.49	0.60
0	0	1	0	1	0	1	0	15	1.79	0.78
0	0	1	1	0	0	0	1	16	1.59	0.66
0	0	1	0	0	1	1	0	17	1.87	0.82
0	0	1	1	0	0	1	0	18	2.18	1.00

Histograms in Figures 21 through 23 display the results of the ConjointHI values using the new attribute-worths from Table 24 and Equation 17. Variations of the equation are also used to perform a sensitivity analysis. Figure 22 replaces the multiplying factor of 10 with 20, to review which value will most reasonably affect the health index. With an alteration allowance of 10, Figure 21 is similar to the unaltered ConjointHI histogram. However, peaks in the original ConjointHI chart are now more dispersed, when compared to original health indexes. Such as in Figure 23 there was a peak in health score ranging 50 to 55. However, when the new attribute-worths are applied Figure 21 displays a peak in the range of 46 to 48 and smaller dispersed peaks in the ranges of 48 to 50 and 50 to 52. The new attribute-worths alter the health index moderately. This allows for attributes to adjust values down by a maximum of 10 points. This also allows for the bulk of the health index to be dependent on the inspection observations while indirect attributes such as those defined in section 2.2 moderately affect the health index. Figure 22 has similar groupings of peaks and valleys as those in Figure 21, however values seem to decrease more. Therefore, it can be concluded that the greater the multiplying factor, such as 20, the more health index scores are affected.

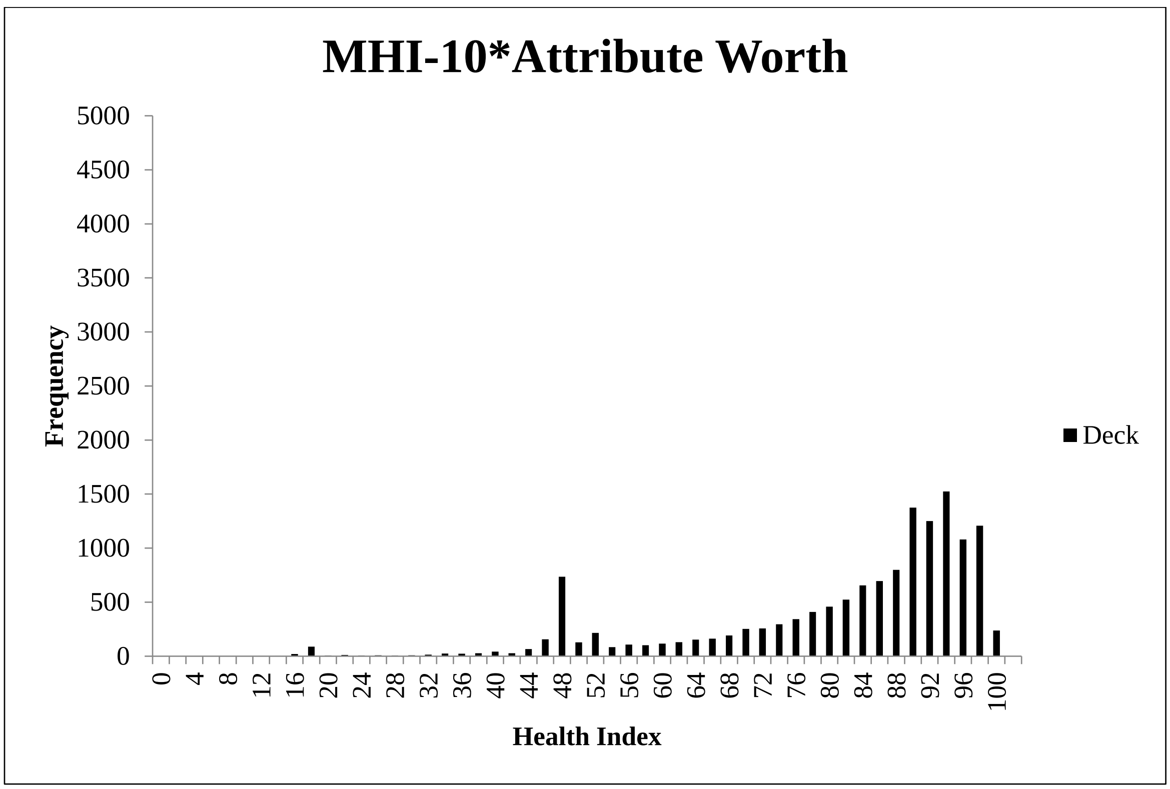

Figure 21 – Deck ConjointHI values with New Rescaled Attribute-Worth Values (10).

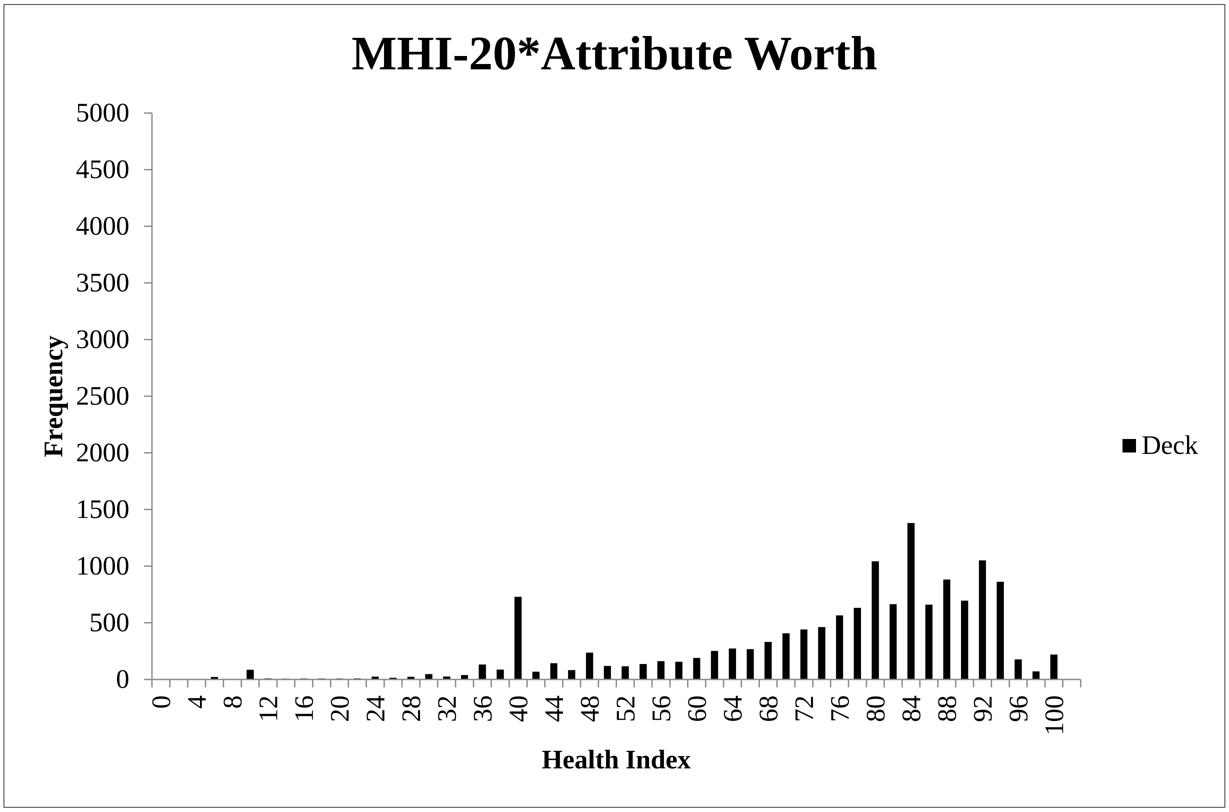

Figure 22 – Deck ConjointHI values with New Rescaled Attribute-Worth Values (20).

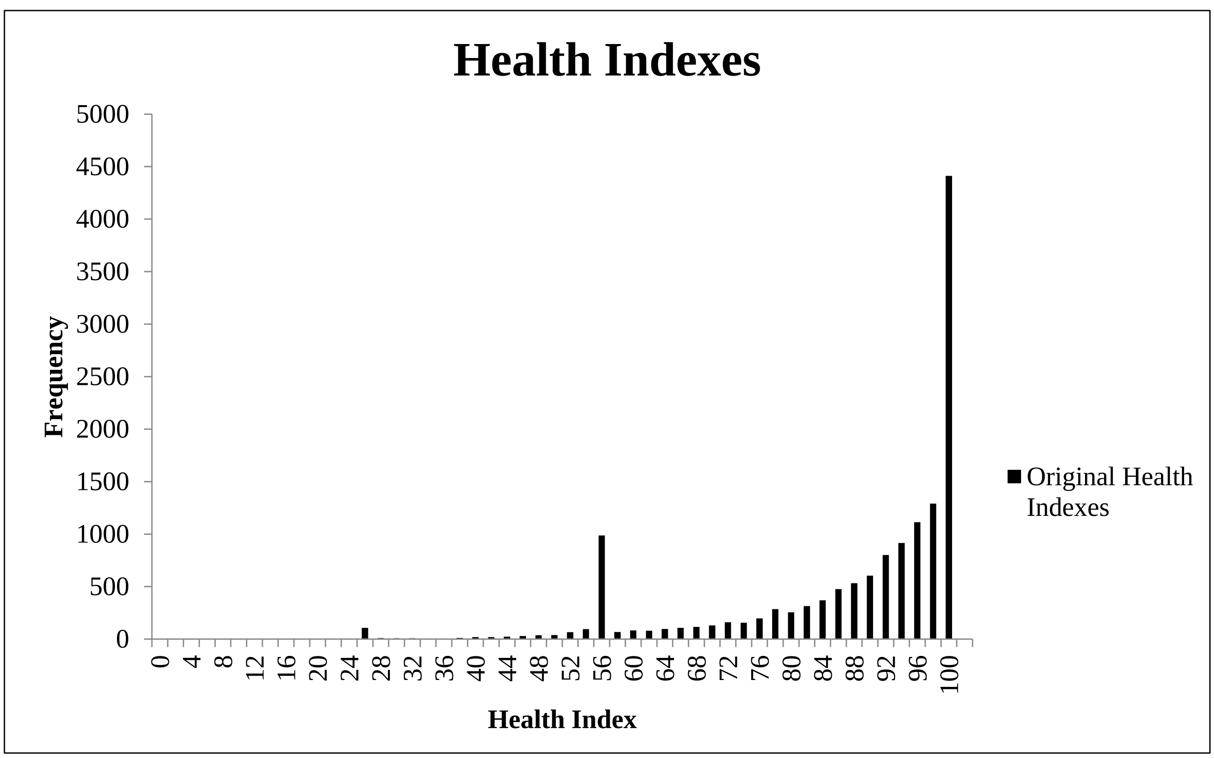

Figure 23 – Original Health Indexes.

3.2 Comparison of Conjoint Analysis Results

3.2.1 *Deck vs. Superstructure and Substructure*

The process of determining preferences, solving for β, and determining total scores to determine attribute-worths as seen in methodology Section 2.2 and results Section 3.1 is repeated for the bridge superstructure and substructure. The bridge deck, superstructure, and substructure will all go through a conjoint analysis process to determine attribute-worth values, or preferences, for the year, region, and presence of waterway. The rescaled attribute-worths and their corresponding ranks for the three bridge components will then be combined to determine an overall modified health index score for a bridge, MHI_{BR}, as shown in the bridge asset valuation Section 4.1. The rescaled attribute-worths will be applied to original health indexes, to then be summed to obtain the $MHI_{BR.}$

Results for the conjoint analysis of the superstructure are displayed in Table 22. The percentage of preferences are also displayed in Table 23. Rank 18 is the circumstance year < 1980, Northern, and waterway. While Rank 1 is the condition of year < 2020, Central, and Non-waterway. Similar to the bridge deck, year < 1980 and waterway were considered most detrimental to bridge health. However, superstructure has a higher percentage for waterway than the deck does. This is because the superstructure is more susceptible to damage when exposed to water. Northern, is favored as the most harmful region for the superstructure because of the colder temperatures of North Georgia. These colder temperatures can cause harm, such as from freeze thaw conditions. However, Southern follows behind closely because extremely high temperatures are not good for the superstructure as well.

Table 22 –Attribute-Worth for Bridge Superstructure

YR < 2020 (x1)	YR < 2000 (x2)	YR < 1980 (x3)	Central (x5)	Southern (x6)	Northern (x4)	Non-Waterway (x8)	Waterway (x7)	Rank (y)	Total Score	Attribute-Worth
1	0	0	1	0	0	1	0	1	0.42	0.01
1	0	0	0	1	0	1	0	2	0.53	0.07
1	0	0	0	0	1	1	0	3	0.78	0.21
0	1	0	1	0	0	1	0	4	0.51	0.06
0	1	0	0	1	0	1	0	5	0.63	0.13
1	0	0	1	0	0	0	1	6	1.03	0.35
0	1	0	0	0	1	1	0	7	0.88	0.27
1	0	0	0	1	0	0	1	8	1.14	0.42
1	0	0	0	0	1	0	1	9	1.39	0.56
0	0	1	1	0	0	1	0	10	1.18	0.44
0	1	0	1	0	0	0	1	11	1.12	0.41
0	1	0	0	1	0	0	1	12	1.23	0.47
0	1	0	0	0	1	0	1	13	1.48	0.62
0	0	1	0	1	0	1	0	14	1.30	0.51
0	0	1	1	0	0	0	1	15	1.79	0.79
0	0	1	0	1	0	0	1	16	1.90	0.86
0	0	1	0	0	1	1	0	17	1.54	0.65
0	0	1	0	0	1	0	1	18	2.15	1.00

Table 23 – Percentage of Preferences for Bridge Superstructure

YR < 2020 (x1)	YR < 2000 (x2)	YR < 1980 (x3)	Central (x5)	Southern (x6)	Northern (x4)	Non-Waterway (x8)	Waterway (x7)
5%	14%	81%	17%	29%	54%	20%	80%

A conjoint analysis was also performed on the bridge substructure; results are shown in Table 24. The preferences for year, region, and presence of waterway can also be found in Table 25. Rank 18 is the condition of year < 1980, Southern, and waterway. Rank 1 is the circumstance of year < 2020, Central, and non-waterway. Similarly to the superstructure and deck, the year <1980 and waterway are determined to be most concerning for the bridges health. Because older bridges have a greater chance for structural problems as they age. Presence of water can cause corrosion, cracking, and harm to members such as the bridge piers that are susceptible to this damage. Therefore, presence of waterway has a high percentage because of the potential for harm to the substructure. For region, Southern is considered to be the most detrimental. Because, based upon studies of condition ratings for bridges in Southern Georgia the substructure was in worst condition in the South when compared to North and Central regions. The poor conditions have been attributed to the warmer temperatures in the South. The Central region was not a high priority for harm to the substructure because of the area's moderate temperatures. Unlike the increasing heat and cold in the Northern and Southern Regions.

Table 24 – Attribute Worth for Bridge Substructure

YR < 2020 (x1)	YR < 2000 (x2)	YR < 1980 (x3)	Central (x5)	Southern (x6)	Northern (x4)	Non-Waterway (x8)	Waterway (x7)	Rank (y)	Total Score	Attribute-Worth
1	0	0	1	0	0	1	0	1	0.42	0.00
1	0	0	0	0	1	1	0	2	0.51	0.06
1	0	0	0	1	0	1	0	3	0.69	0.16
0	1	0	1	0	0	1	0	4	0.53	0.06
0	1	0	0	0	1	1	0	5	0.62	0.12
0	1	0	0	1	0	1	0	6	0.79	0.22
1	0	0	1	0	0	0	1	7	1.12	0.41
1	0	0	0	0	1	0	1	8	1.21	0.47
1	0	0	0	1	0	0	1	9	1.38	0.57
0	0	1	1	0	0	1	0	10	1.15	0.43
0	1	0	1	0	0	0	1	11	1.22	0.47
0	1	0	0	0	1	0	1	12	1.31	0.53
0	0	1	0	0	1	1	0	13	1.24	0.49
0	0	1	0	1	0	1	0	14	1.42	0.59
0	1	0	0	1	0	0	1	15	1.49	0.63
0	0	1	1	0	0	0	1	16	1.84	0.84
0	0	1	0	0	1	0	1	17	1.94	0.90
0	0	1	0	1	0	0	1	18	2.11	1.00

Table 25 – Percentage of Preferences for Bridge Substructure

YR < 2020 (x1)	YR < 2000 (x2)	YR < 1980 (x3)	Central (x5)	Southern (x6)	Northern (x4)	Non-Waterway (x8)	Waterway (x7)
6%	16%	78%	21%	48%	31%	15%	85%

When comparing the deck, substructure, and superstructure health indexes, once the attribute-worths are applied, the trends are generally similar. For all three components, a majority of bridges fall under health index scores from 80 to 100, and have a peak around 50. However, there are slight differences between the data sets. Such as for a score of 94, superstructure contains the most bridges. On the other hand, for a score of 48 the deck contains the most number of bridges. These slight differences in deck, substructure, and superstructure health indexes can be attributed to the difference in preferences for year, region, and presence of waterway. Superstructure's higher number of bridges for health indexes of 94 can be attributed to the fact that Northern has the highest preference for superstructure and bridges in the Northern region are in better condition than those in the Central and Southern. All trends in bridge components can be attributed to the percentage of preference in the year, region, or presence of waterway.

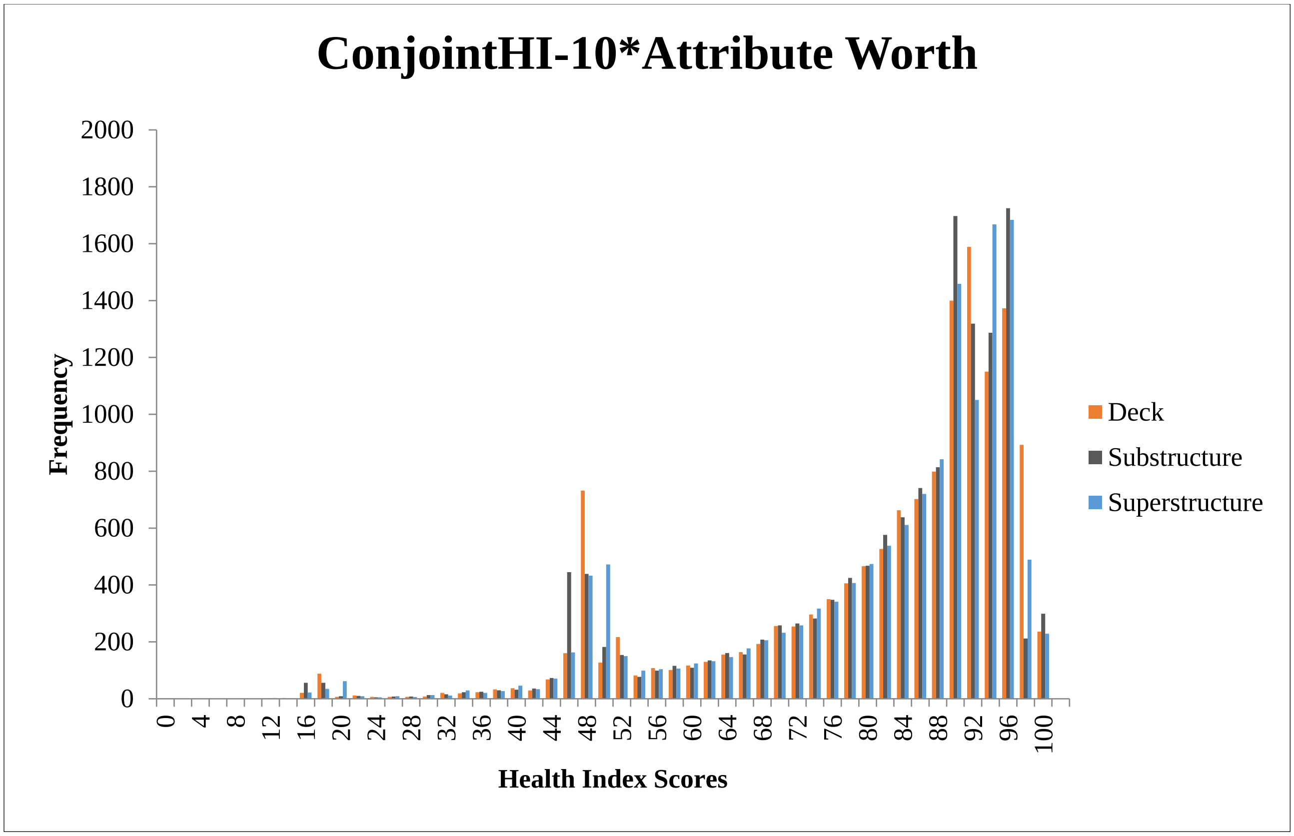

Figure 24 – Deck, Substructure, Superstructure Comparison.

3.2.2 *Coastal vs. Southern*

GDOT engineers also requested a sensitivity analysis be done on the region, specifically the Southern region. Therefore, Southern was exchanged for Coastal and a conjoint analysis was conducted for the deck, superstructure, and substructure again. The coastal region is defined by the counties, of Southeast Georgia, that are near the coast of Georgia. Seventeen counties are defined as Coastal in Georgia, because of their similar weather patterns. These Coastal counties have a climate of hot summers, cool winters, and few hard freezes. Rain is usually above average, and seasonal. Because of the Coastal region's unique weather patterns, a conjoint analysis was done to determine if there are differences between it and the South. South Georgia includes counties in the bottom half of Georgia, including the Coastal region. The typical weather climate in this region is short, mild winters, long hot summers, with moderate to heavy rain. The differentiation between Southern and Coastal Georgia can be seen in the figures below.

Figure 25- North, Central, and Southern/Coastal Georgia.

The conjoint analysis produced identical results as those with the Southern region. This can be attributed to the extremely similar weather conditions in the Southern and Coastal regions, as well as the Southern region encompassing the Coastal region. As shown in Figure 25, they are located in similar regions of Georgia. Therefore, there is not significant differences between attribute-worth values and modified health indexes. The attribute-worths produced from the coastal region are displayed below.

Table 26 – Rescaled Attribute worth for Coastal instead of Southern

Rank (y)	Deck	Superstructure	Substructure
1	0.00	0.01	0.00
2	0.04	0.07	0.06
3	0.04	0.21	0.16
4	0.08	0.06	0.06
5	0.22	0.13	0.12
6	0.34	0.35	0.22
7	0.38	0.27	0.41
8	0.26	0.42	0.47
9	0.56	0.56	0.57
10	0.38	0.44	0.43
11	0.42	0.41	0.47
12	0.44	0.47	0.53
13	0.48	0.62	0.49
14	0.6	0.51	0.59
15	0.78	0.79	0.63
16	0.66	0.86	0.84
17	0.82	0.65	0.90
18	1.00	1.00	1.00

Figure 26 to 31 show the result of the attribute-worths being applied individually to the bridge deck, superstructure, and substructure. The attribute-worth is applied to Northern, Central, and Coastal for Figures 26, 28, 30. For Figures 27, 29, and 31 the attribute-worth is applied to Northern, Central, and, Southern. When comparing the Southern and Coastal results there is not much variation between the results data. While Southern and Coastal have the same set of attribute-worth data, the regions vary. This results in differentiation between ranks applied to the health indexes for the two sets of data. The similarity in attribute-worth values is the cause of the resemblance in results between all data figures. Trends can be seen between all of the results. For all three components, there is a spike in bridges with a MHI around 48. Indicating that all data sets are following the same pattern. For all bridge components, most scores range between 80 and 100.

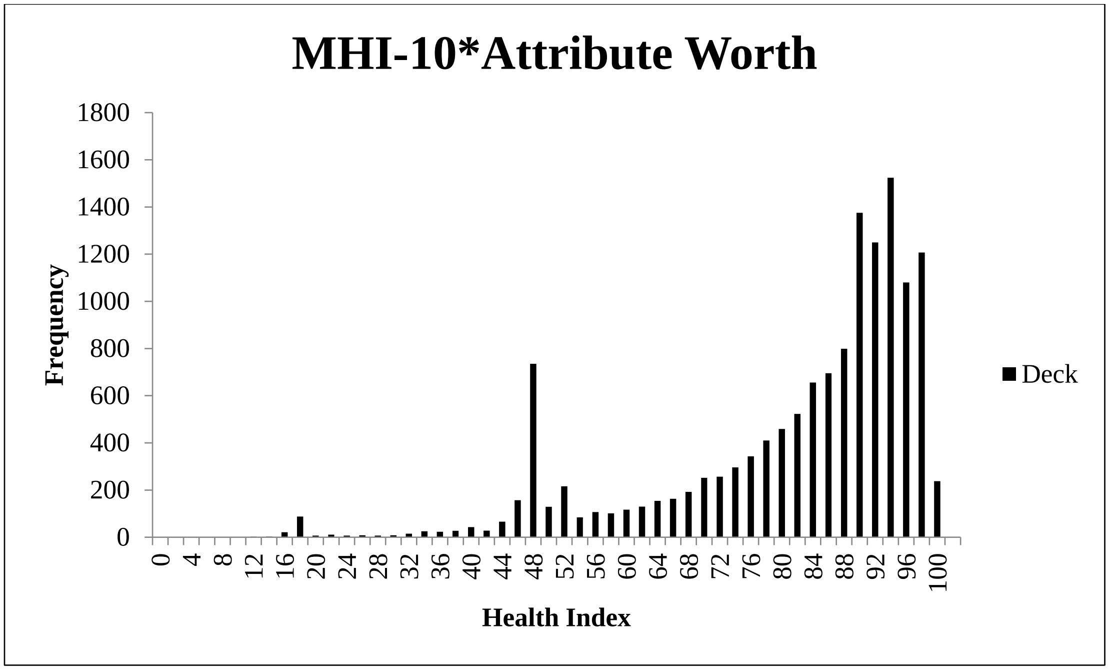

Figure 26 – ConjointHI of Deck Coastal.

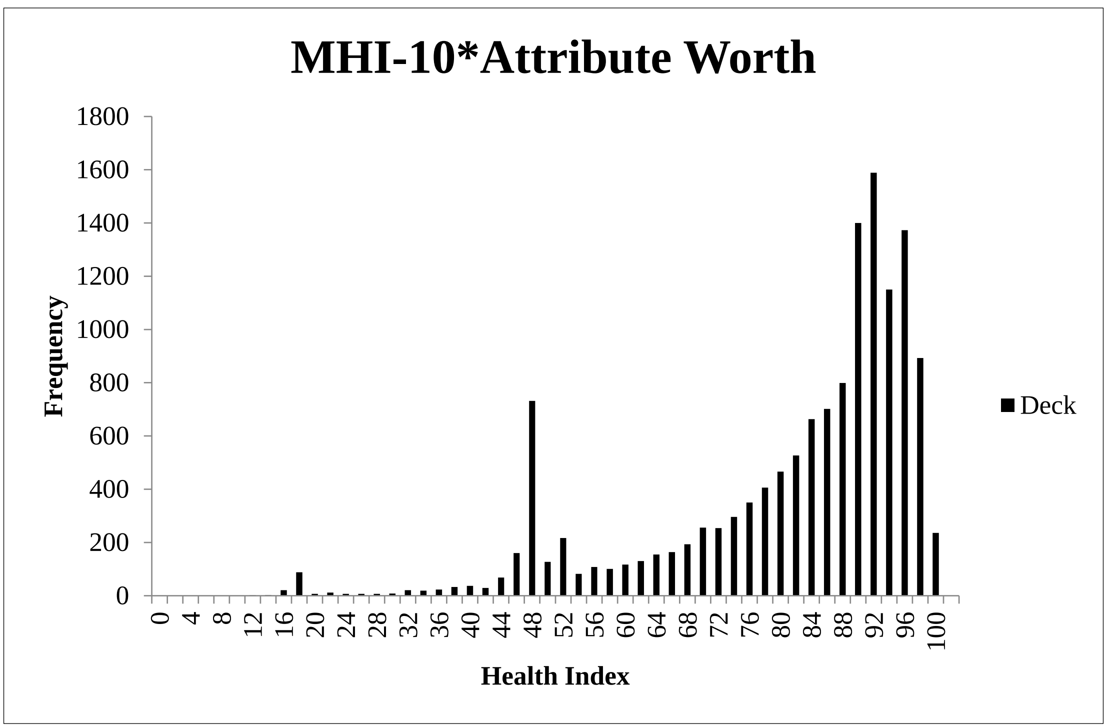

Figure 27 –ConjointHI of Deck Southern.

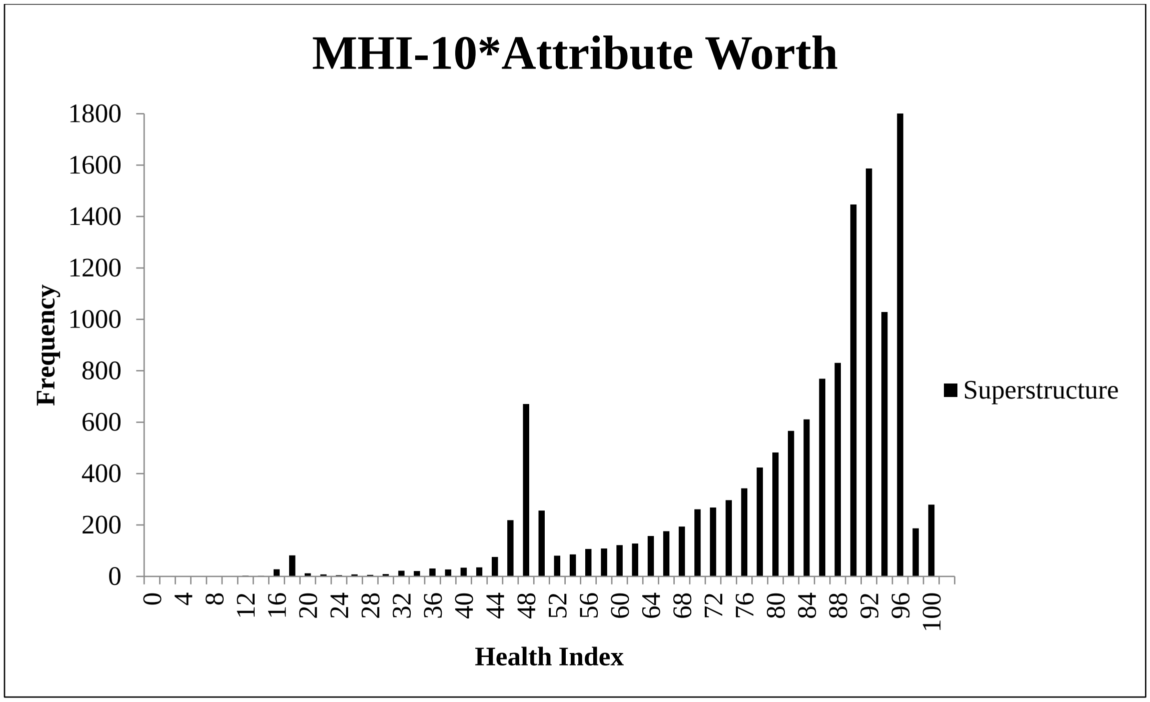

Figure 28 – ConjointHI of Superstructure Coastal.

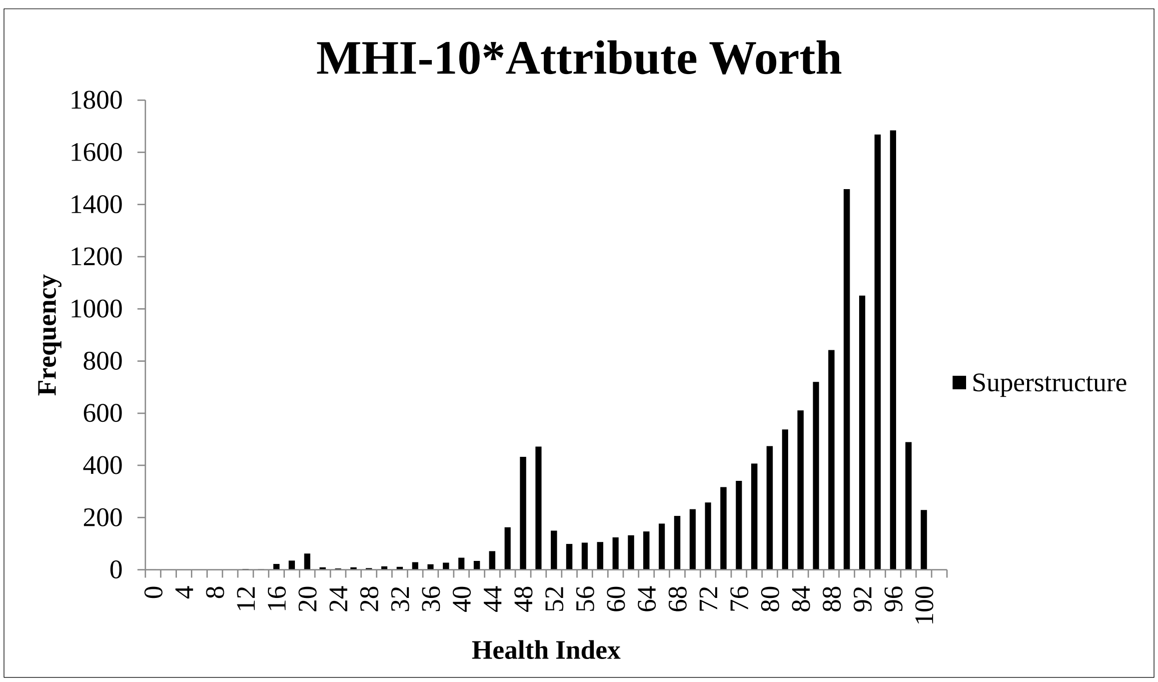

Figure 29 - ConjointHI of Superstructure Southern.

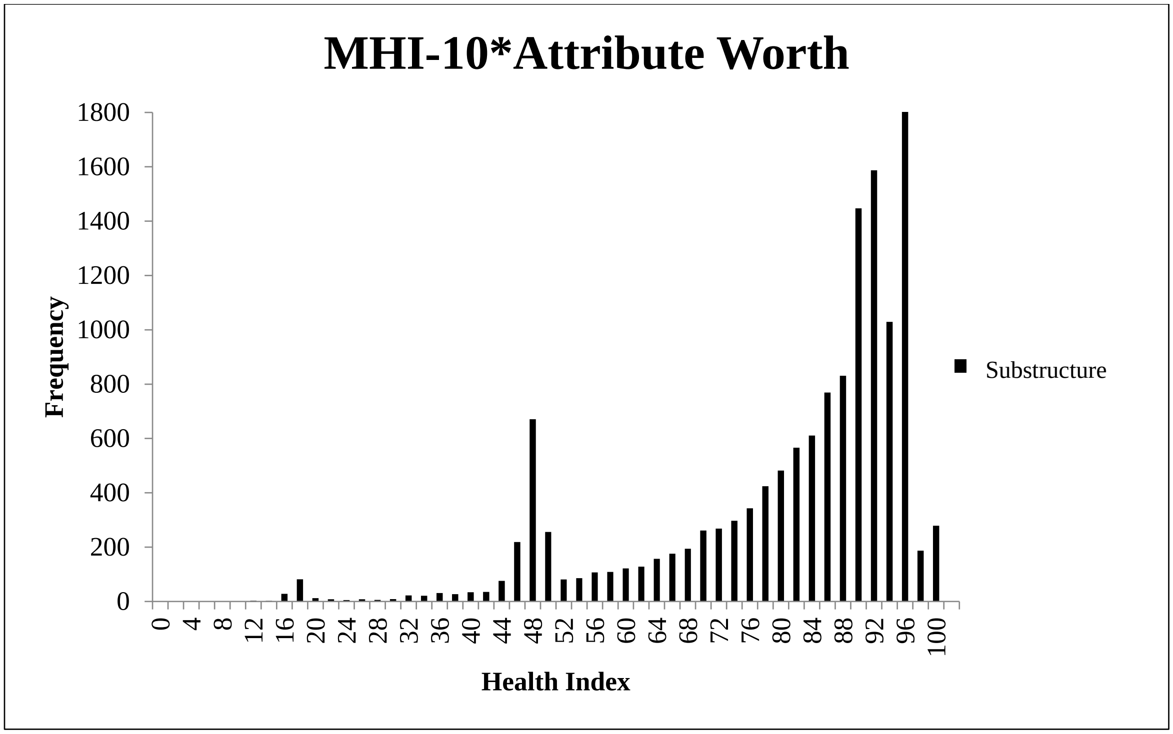

Figure 30 – ConjointHI of Substructure Coastal.

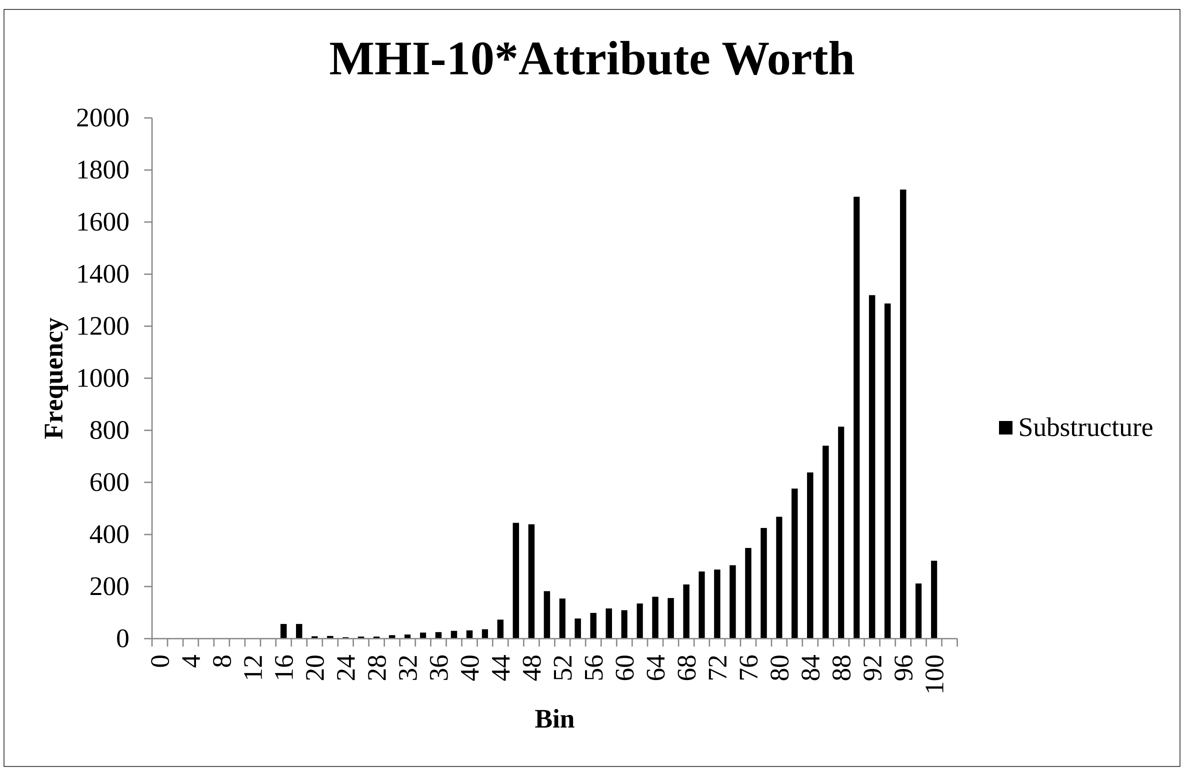

Figure 31 - ConjointHI Substructure Southern.

3.2.3 *Bridges vs. Culverts*

Georgia's bridge data can be separated between bridges and culverts. The technical difference between the two structures is the span length. A bridge is typically defined by Department of Transportation and National Bridge Inventory as being 20 feet or longer, otherwise it is considered to be a culvert. Bridges and culverts are also able to be differentiated by their uses. A culvert is typically used to carry water under a roadway. While a bridge can be used to span water or land. A bridge's typical function is for passage, crossing, while a culvert is a tunnel structure not intended for human use. Some engineers prefer to separate culvert data during bridge inspections or maintenance analysis, while others prefer to have all of the bridge and culvert information together. An analysis was done to calculate the Modified health Index, after attribute-worths are applied, for bridges alone, and then all of the infrastructure together.

There are a total of 4506 culverts and 7034 bridges with health indexes that were able to be modified. When comparing the health of the two structures, shown in Figures 32 and 33, the bridges appear to be in better health. A majority of the bridges lie in the range of 70 to 100. Based upon GDOT standards and criteria the bridges are in good health, as a majority are above 70. While a majority of culverts are at health index value 48 or 92. A good amount of the culvers to lie between 70 to 100, however, there is a spike in the number of bridges around the health index score of 48. This could be because engineers tend to disregard culverts or bridges below a health index of 50, causing the structures to constantly decrease in score as years pass. Structures with score less than 50 are generally disregarded because it would cost more to increase the score to a 70 than the bridge is actually worth. Overall, based upon health index scores, bridges are in better condition than culverts. Also, bridges appear to have better upkeep and maintenance than culverts based upon the high number of bridges above a modified health index value of 70.

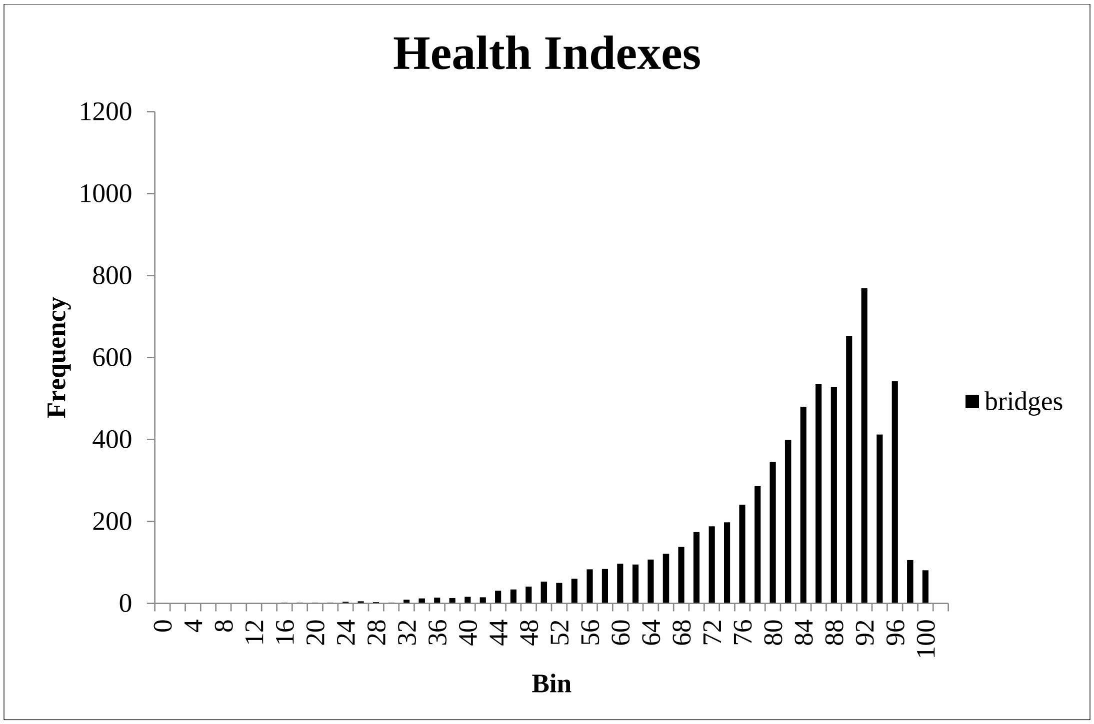

Figure 32 - Bridges Only Health Index.

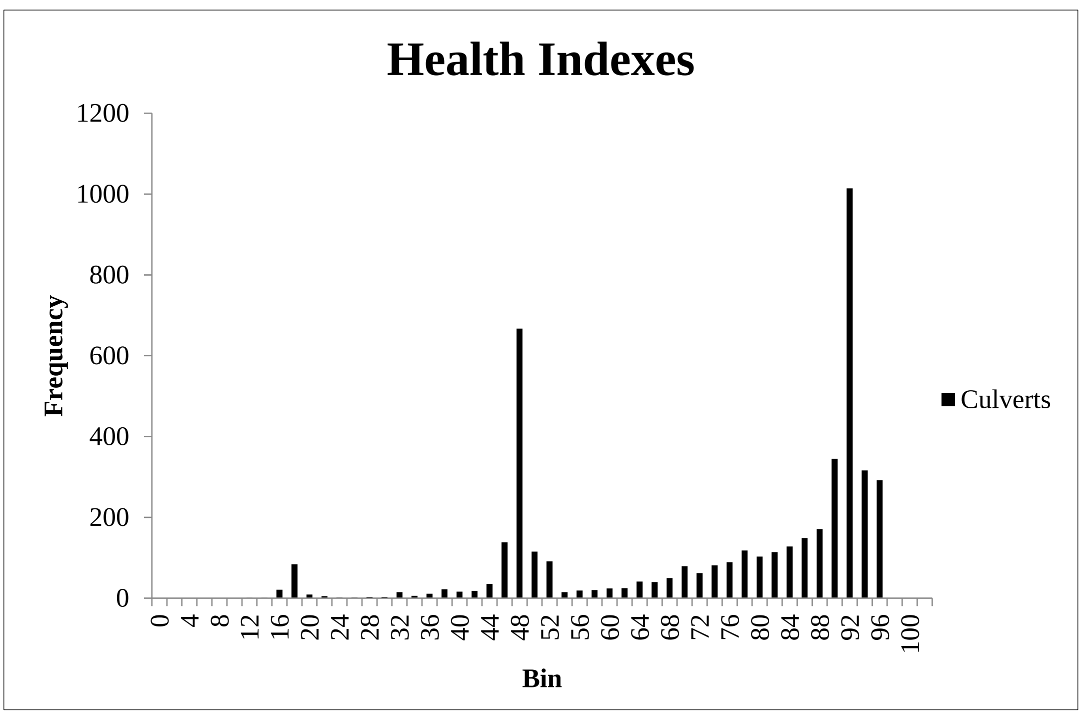

Figure 33 – Culvert Only Health Index.

When comparing the total combined modified health index values from Figure 35, MHI_{BR}, to the bridge only and culvert only modified health indexes it is possible to see how the $MHII_{BR}$ values are formed. Figure 35 sows a spike in values at 48 and 96, which can be attributed to the culverts. Figure 35 also shows a majority of health indexes above 80, which can be attributed to the bridge only scores. The bridges and culverts combine and their inflections are imposed upon the total modified health index scores.

3.3 Summary

Overall, the element cost database, conjoint analysis, and asset valuation work together to complete the task of assigning monetary value to Georgia's bridges. The collection of element costs acts as a check for the cash flow analysis, by verifying bridge expenses. While the cash flow analysis uses the modified health indexes created from the conjoint analysis. The conjoint analysis, in turn, is able to produce the accurate bridge health indexes using attribute-worths. Table 27 summarizes the proposed attribute-worths including the coastal region (see Fig. 25).

Table 27 – Percentage of Preferences for Bridge Deck, Superstructure, and Substructure

Bridge component	YR < 2020 (x1)	YR < 2000 (x2)	YR < 1980 (x3)	Central (x5)	Southern (x6)	Northern (x4)	Non-Waterway (x8)	Waterway (x7)
Deck	5%	13%	82%	18%	25%	57%	20%	80%
Superstructure	5%	14%	81%	17%	29%	54%	20%	80%
Substructure	6%	16%	78%	21%	48%	31%	15%	85%

4. ASSET VALUATION RESULTS

4.1 Bridge Asset Valuation as Benefit

The initial bridge construction cost will be multiplied by a modified health index, MHI_{BR}, to assess a bridge's worth (or benefit to GDOT). Although the time value of the initial construction cost may be considered, a depreciation of asset over its economic life does not generally involve inflation unless it is significant. However, the effect of inflation on the net cost of construction (or replacement cost) may be considered in the future.

By indexing depreciation by means of a conjoint analysis-modified health index (conjointHI), one can completely eliminate adjusting depreciation in an inflationary economy. MHI_{BR} values are the combination of ConjointHI values for the deck, superstructure, and substructure. Defining MHI_{BR} is the final step in the asset valuation process using a conjoint analysis approach. The MHI_{BR} is a value that will be able to fully define a bridge's health taking in inspection factors and attribute factors defined during the conjoint analysis. Therefore, an accurate assessment of MHI_{BR} is critically important for bridge asset valuation.

The MHI_{BR} is able to be determined using the following equation:

MHI_{BR} = 0.25*(Deck ConjointHI with attribute-worths applied) + 0.35*(Superstructure ConjointHI with attribute-worths applied) + 0.40*(Substructure ConjointHI with attribute-worths applied) **Eq. 18**

The bridge deck, superstructure, and substructure attribute-worths are applied to the original health index separately, as seen in Section 3.2 of the conjoint analysis results. For each bridge component, the year of construction, region, and presence of waterway are determined so they can then be matched up with the corresponding rank and attribute-worth. Then, the health indexes determined from that process are multiplied by 0.25 for the deck, 0.35 for the superstructure, and 0.40 for the substructure. These values are then summed together to get the final bridge health index value, MHI_{BR}. The values of 0.25, 0.35, and 0.40 are representative of the importance of these components in a bridge structure. Substructure is given the largest value of 0.40 because it is most important. If the substructure fails, the bridge cannot be repaired easily. In contrast, the deck is the least important component of the bridge, and can be easily replaced, hence its value of 0.25. The superstructure is valued at 0.35, as it is more structurally important than the deck. The superstructure is vital to the integrity of the bridge, however; it will not be as detrimental in failure as the substructure would.

MHI_{BR} is a combination of the deck, superstructure, and substructure, conjoint and health index values. The overall bridge health scores are representative of preferences established in the conjoint analysis as well as a percentage of importance in comparison to the entire bridge structure. The final set of MHI_{BR} values developed from Eq. 18 are displayed in Figure 35. When comparing the original unmodified health indexes to those of the MHI_{BR}, a general trend in health index values is clear. The majority of values range between 80 and 100. The number of bridges starts to decrease as the scores diverge from 80. Around a health index of 50, for both charts, there is a sudden increase in the number of bridges. While MHI_{BR} and the original health indexes follow the same pattern, there are differences between the two sets of values. When MHI_{BR} values are compared to original values, more variation is observed. Unlike the original values that follow a constant, uniform, decrease in number of bridges as the health index also decreases. MHI_{BR} values do decrease on a linear basis, in general, but there are instances where values are more sporadic. Such as in the range of 88 to 100, the values generally decrease, however, 94 stands out as a value that does not follow the average decreasing trend. This variation is a positive aspect of the modified bridge health indexes. The differentiation between values emphasizes the importance in health indexes. The differentiation will allow for easier decision making than the uniformity of the original health index, which made decision making more difficult. The variation in the values allows for a more accurate health index that is able to account for indirect environmental factors. Furthermore, this distribution in MHI_{BR} values makes it easier for engineers to decide between repair or replacement because health indexes are spread out between categories.

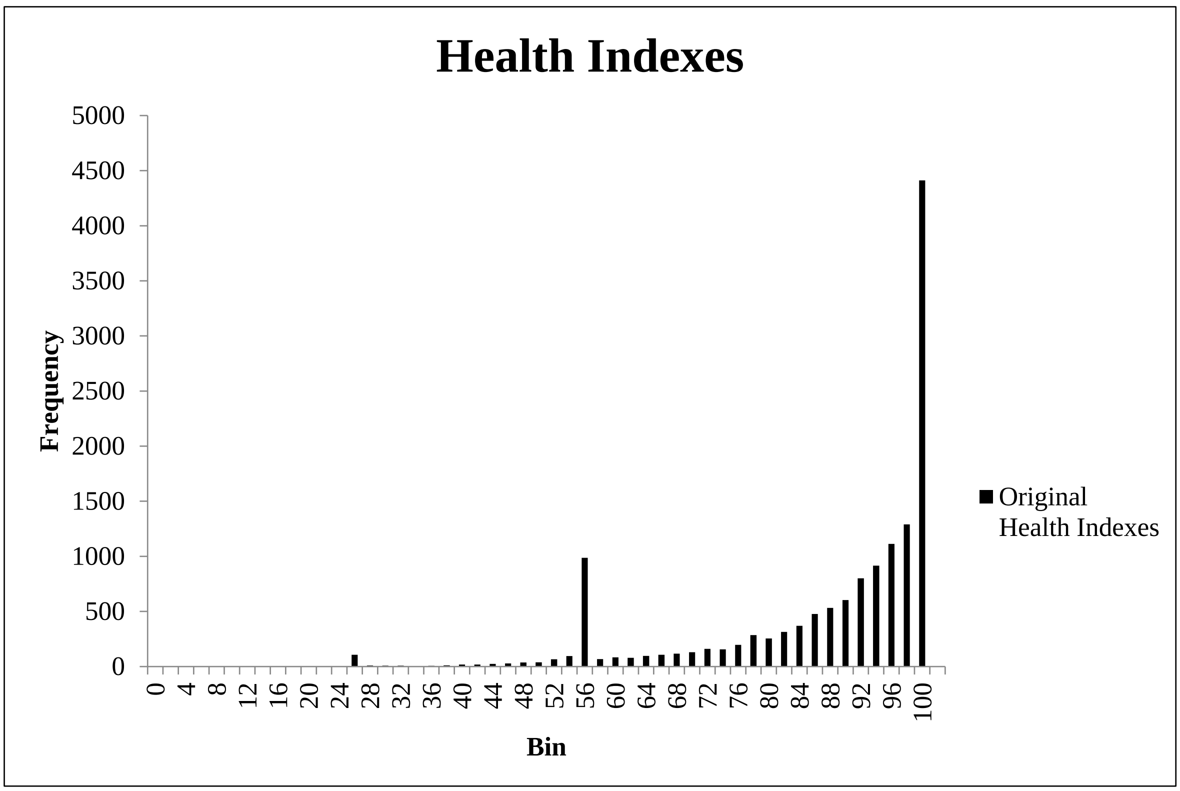

Figure 34– Original Unmodified Health Indexes.

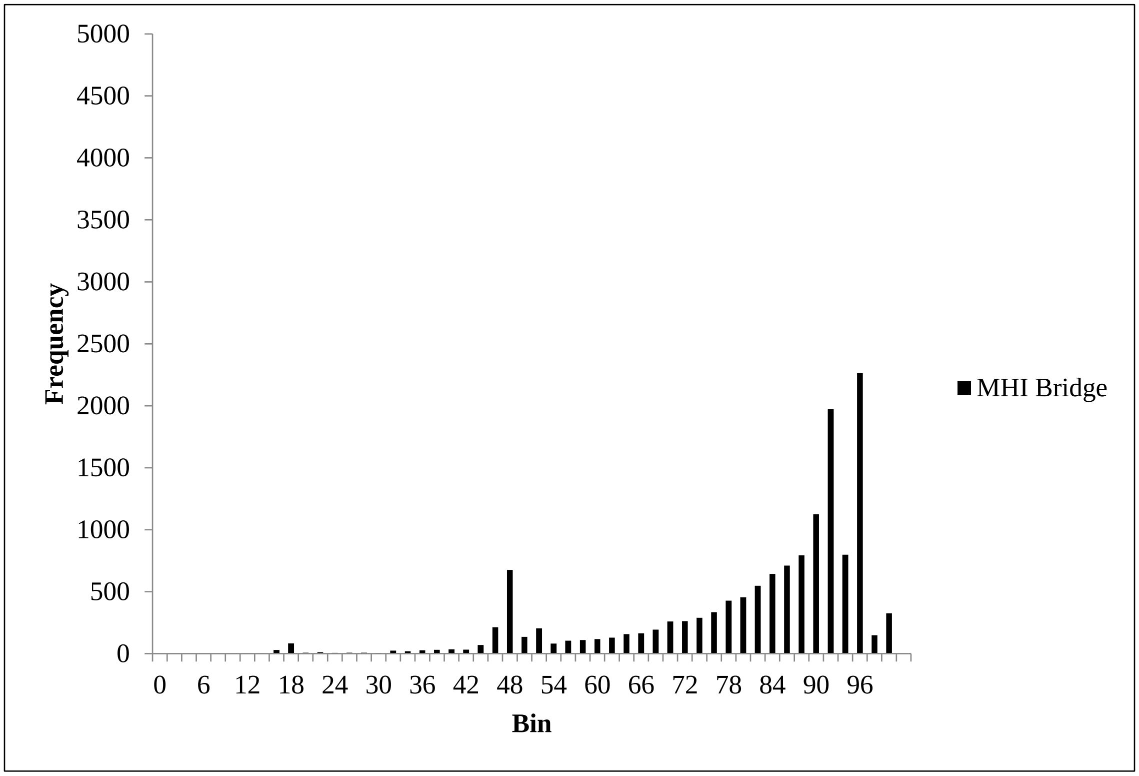

Figure 35 – MHI_{BR} Health Index values Coastal.

4.2 Element Cost Database

For the bridge elements that were selected, element unit cost data was able to be collected. The difficulty in tracking down some elements could be attributed to their rarity in use, or an element's specificity to Georgia can explain why they are not seen outside of the state. Generally, it was easier to find valuable information from years 201l through 2018. Prior to 2011, finding unit costs figures proved to be more difficult. This could be due to the primary use of paper documentation for construction documents until later in the 2000's, when keeping electronic documents gained popularity. Thirty percent of the elements defined as important to Georgia have recorded element cost data in the database, after navigating excel files received from GDOT-Construction Bidding and performing a literature review. These elements are displayed in Table 28 and are often expanded upon into specifics. For instance, when documenting the category of AASHTO girders, the original defined element was expanded upon to include specifics on unit costs for each type of AASHTO girder, I through VI.

To analyze the current available data within the element cost database, selected elements were examined because of their consecutive unit cost data. Data is classified as consecutive when for repeated years a unit cost is recorded in the database for an element. For instance, steel piles had unit cost data recorded in years 2016, 2017, and 2018. Data is not considered consecutive when there is missing cost information for a year, or years. The timber deck element only had recorded element cost information in 2010, 2012, and 2013. Most elements had a combination of consecutive and non-consecutive data, where there was an abundance of information for many years; however, one or two years were missing information. As illustrated in Table 29, some elements that have consecutive unit cost data were Prestressed Concrete Closed Web/Box Girder, AASHTO Type I-VI Girders, Prestressed Concrete Piles, and Steel Piles.

Table 28 - Element Unit Cost Data Collected

Unit Cost Data Discovered	Unit	Minimum Unit Cost ($)	Maximum Unit Cost ($)
Steel Deck with Concrete Filled Grid	Area (sq. ft.)	83.00	84.00
Timber Deck	Length (ft.)	90.26	90.26
Reinforced Concrete Slab: Simple Span	Length (ft.)	160.00	160.00
Prestressed Concrete Closed Web/Box Girder	Length (ft.)	112.00	595.00
Prestressed Concrete Open Girder/Beam	Length (ft.)	55.00	207.39
Steel Box Girder (unspecified closed/open)	Pound (lb.)	1.32	2.15
Steel Truss	Length (ft.)	121.96	126.57
Reinforced Concrete Arch	Length (ft.)	44.03	235.00
Prestressed Concrete Column	Each	43122.08	43122.08
Reinforced Concrete Column	Each	26591.96	26591.96
Reinforced Concrete Abutment	Length (ft.)	4509.25	4509.25
Steel Pile	Length (ft.)	17.23	200.00
Prestressed Concrete Pile	Length (ft.)	25.00	175.00
Timber Pier Cap	Length (ft.)	3795.61	3795.61
Prestressed Concrete Culvert	Length (ft.)	7500.00	7500.00
Strip Seal Expansion Joint	Length (ft.)	106.00	350.00
Pourable Joint Seal	Length (ft.)	293.50	293.50
Elastomeric Bearing	Each	6451.10	6451.10
Fixed Bearing	Each	2000.00	2000.00
Pot Bearing	Each	35000.00	100100.35
Concrete Bridge railing	Length (ft.)	786.98	786.98
Steel Guardrail	Length (ft.)	15.39	122.64

Table 29 - Unit (per foot) Costs Excerpt for Selected Elements

	2011	2012	2013	2014	2015	2016	2017
Prestressed Concrete Closed Web/Box Girder Box Beam 17" x 36"	175.00	179.44	156.55	201.29	193.96	244.67	218.57
AASHTO Girder AASHTO Type II	134.21	130.00	113.86	141.07	129.32	159.34	150.17
Prestressed Concrete Pile 16” Piling	47.00	51.92	53.75	52.80	34.00	85.00	61.95
Steel Pile 10" Pile	40.33	41.16	39.44	42.78	37.98		

While examining element cost values from 2011 to 2018, a trend could be recognized among Prestressed Concrete Closed Web/Box Girder, AASHTO Type I-VI Girders, Prestressed Concrete Piles, and Steel Piles. The elements have very similar unit cost trends over the six-year period. As shown in Figure 36, prices in 2015 for all four elements decreased. 17” x 36” Prestressed Concrete Closed Web/Box Girders decreased by 3.6%, AASHTO Type II Girders by 3.64%, 16” Prestressed Concrete Piles by 35.61%, and 10” Steel Piles by 11.24%. In the year of 2016, unit cost prices also saw a drastic increase. Unit costs increased by percentages, excluding 10” Steel Piles, 26.1%, 23.2%, and 150%, respectively.

From 2011 to 2017, unit costs have generally increased, with a few dips in 2013, 2015, and 2017. While 10” Steel Piles did increase marginally in many years, the element stayed relatively flat. The similar trend in unit cost data for Prestressed Concrete Closed Web/Box Girder, AASHTO Type I-VI Girders, and Prestressed Concrete Piles may be because of their similar use of concrete material. Therefore, the elements had similar cost fluctuations due to concrete prices throughout the years.

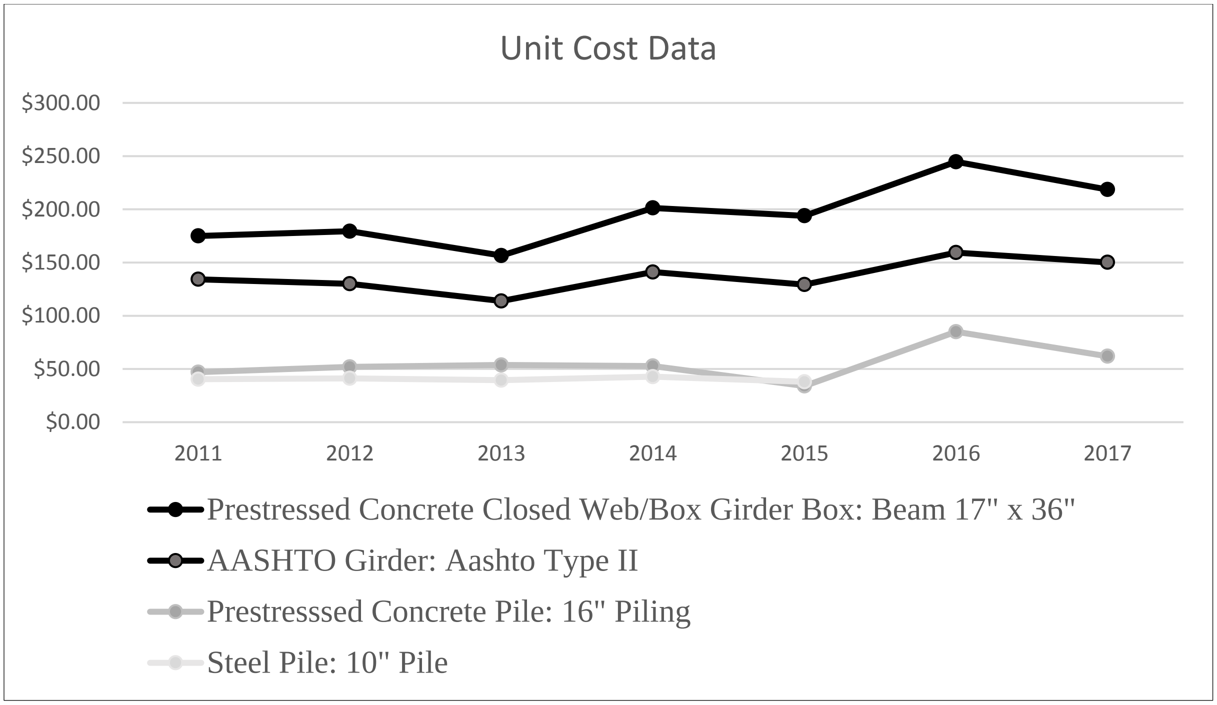

Figure 36 – Element Unit Cost Line Chart.

Because the four element categories being analyzed in Figure 36 are generally increasing throughout the years, it is reasonable to predict their approximate future unit cost in 2018, using a linear forecast of the plotted unit cost values. As displayed in Figure 37, the elements follow an up year and down year pattern, leading one to believe the 2018 element unit costs will increase from the previous year's. While the individual unit costs are accurate because they came directly from a DOT source, 2018 unit costs could only be predicted by analyzing the known values. The predicted 2018 values in Table 30 are calculated using a linear prediction of unit costs defined in Figure 19.

Overall, the unit costs collected for bridge elements were able to give some prediction into future cost trends, thus aiding in determining future bridge costs on an element-by-element basis. This process will be able to assist when determining what rehabilitation practice is most cost effective for a bridge project. Such as when replacing an element, approximate costs can be determined by charting trends. The database will also be able to be used in conjunction with the developed cash flow analysis to determine future rehabilitation practices. For example, the cash flow analysis can be used to determine a bridge's current health, while the element cost database can be used to determine the cost of a particular element based upon judgement from the cash flow analysis. The approximate cost and expense of rehabilitation can be predicted through the unit cost database and the cash flow analysis will be the deciding factor in determining the rehabilitation practice necessary.

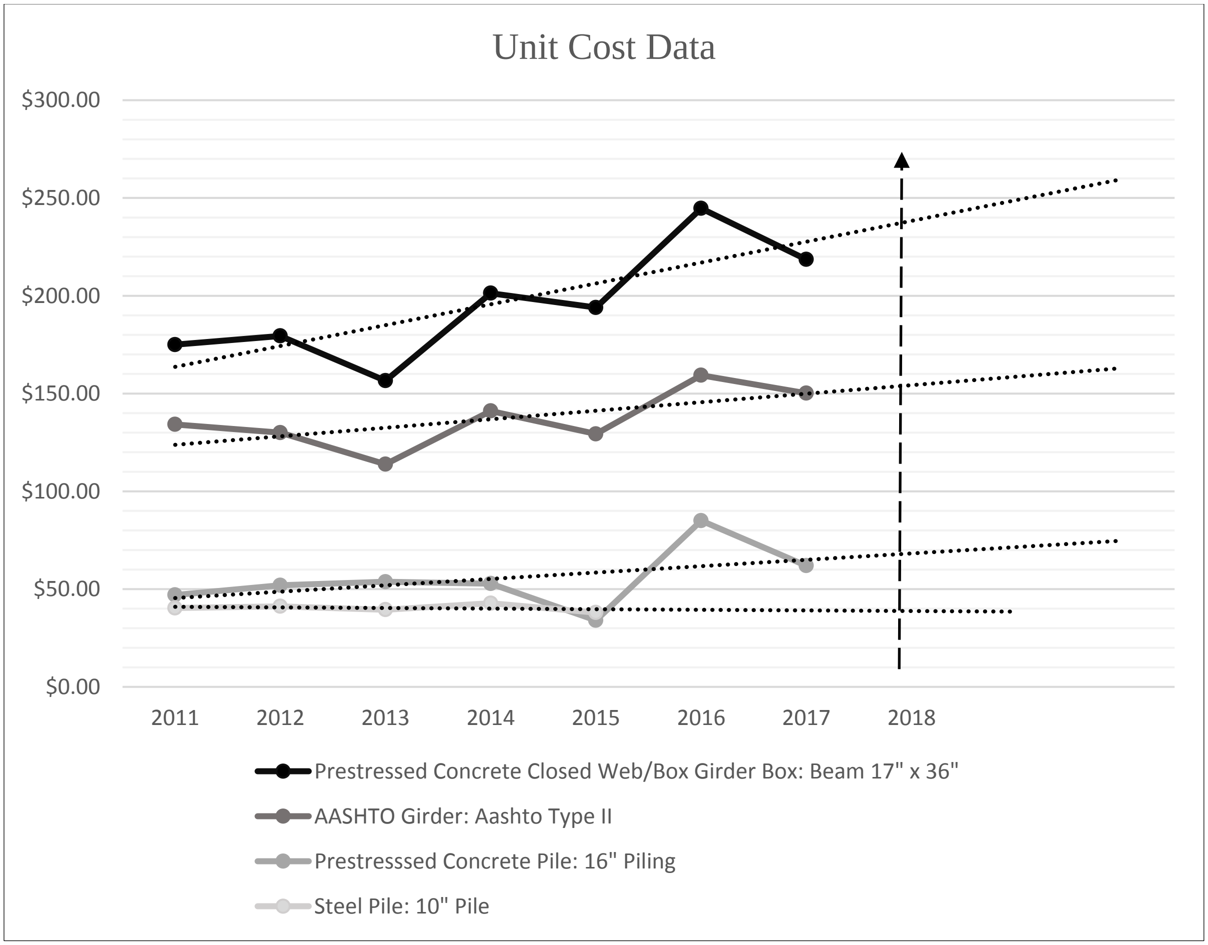

Figure 37 - Unit Cost Excerpt Line Chart with Trend Line.

Table 30- Approximate Predicted Unit Costs

Element	Approximate 2018 Cost ($)
Prestressed Concrete Closed Web/Box Girder Box Beam 17" x 36"	**240.00**
AASHTO Girder AASHTO Type II	**155.00**
Prestressed Concrete Pile 16" Piling	**60.00**
Steel Pile 10" Pile	**40.00**

The trend between Prestressed Concrete Closed Web/Box Girder, AASHTO Girder, Prestressed Concrete Pile, and Steel Pile is the main trend discovered from values in the database.

4.3 Benefit vs. Cost Cash Flow Analysis

Preliminary analysis of bridges with complete information in the designed cash flow analysis system illustrate how the devised analysis tool will be able to provide a clear picture on the health of a bridge. In this section bridges 21300180 and 12104760 cash flow results are analyzed, and future rehabilitation options for the bridges are presented, as an example of what the cash flow tool is capable of. The National Bridge Inventory and GDOT maintenance data are the primary data sourced to form the analysis system.

The figures used from NBI, the total improvement cost, had multiple repeated costs for consecutive years causing scrutiny in whether data was being copied over from the previous years by individuals updating the NBI database. However, the costs could be explained if those same costs were repeated for consecutive years because that was the actual amount allotted toward bridge maintenance for multiple years. To ensure the correct data is available in the NBI files, steps will be taken to have the values confirmed by GDOT. Bridge maintenance data, provided by

GDOT, was available from 2011 to 2018. However, maintenance data obtained from GDOT and the maintenance costs from NBI do not have overlapping costs that occur in the same years. For many bridges, NBI maintenance values appeared in years earlier than 2011 and there was not much data past 2011, if any. Therefore, costs from the two sources did not often overlap.

The calculated benefit of any Georgia bridge was positive because of the benefit equation developed. The benefit equation established in Section 2.4 of the methodology is a measure of a bridge's current equity. The equation developed is the health index multiplied by the initial project cost. The equation uses the health index, divided by 100, so that when the health index is multiplied by the initial project cost a percentage of the cost is taken to compute the benefit. Because of this, the benefit equation will not be a negative value. Having a positive benefit equation is important because, despite the health status of a bridge there will always be a salvage value when it is in need of replacement. The salvage value is the approximate resale value at the end of a bridge's useful life. This means that even if the expenses of a bridge outweigh the historical cost, the bridge still has value. It is important for the bridge to have a positive benefit equation because once it reaches the end of its life, elements of the bridge still have some worth.

Bridge 21300180 and 12104760 are two of the bridges in the database with recorded maintenance costs for both sources, NBI and GDOT. Bridge 21300180's historical cost was defined as $1,278,000, and in 2018 the benefit is calculated at $998,175.48 after 62 years. Bridge 12104760 had an original historical construction cost of $1,383,000. From 1968 to 2018, 50 years, the bridge had 6 recorded instances of maintenance, 3 of which were unique values. The cash flow analysis, shown in Figure 38, of these two bridges visually explains the expenses in their lifetimes.

Based on gathered data displayed in the created cash flow analysis method, bridge 21300180's health Index is currently at 78.10, after modification. The last instance of maintenance was in 2013 where $494,975 was spent. Because of the high health index, and good benefit, regular preventative maintenance is recommended for future work to keep the bridge in its good condition.

- Bridge 21300180 Benefit: (78.10/100) x 1278000 = $998,175.48

Data for bridge 12104760 exhibited maintenance performed from 1968 to 2018. Its current health index is 92.81, after modification, and last recorded maintenance was performed in 2016 at $184,308. The bridges excellent health score could be attributed to the regular maintenance performed. Because maintenance was recently performed and the bridge is in excellent condition no repair or replacement is recommended for years.

- Bridge 121004760 Benefit: (70.29/100) x 1474975 = $1,283,547.50

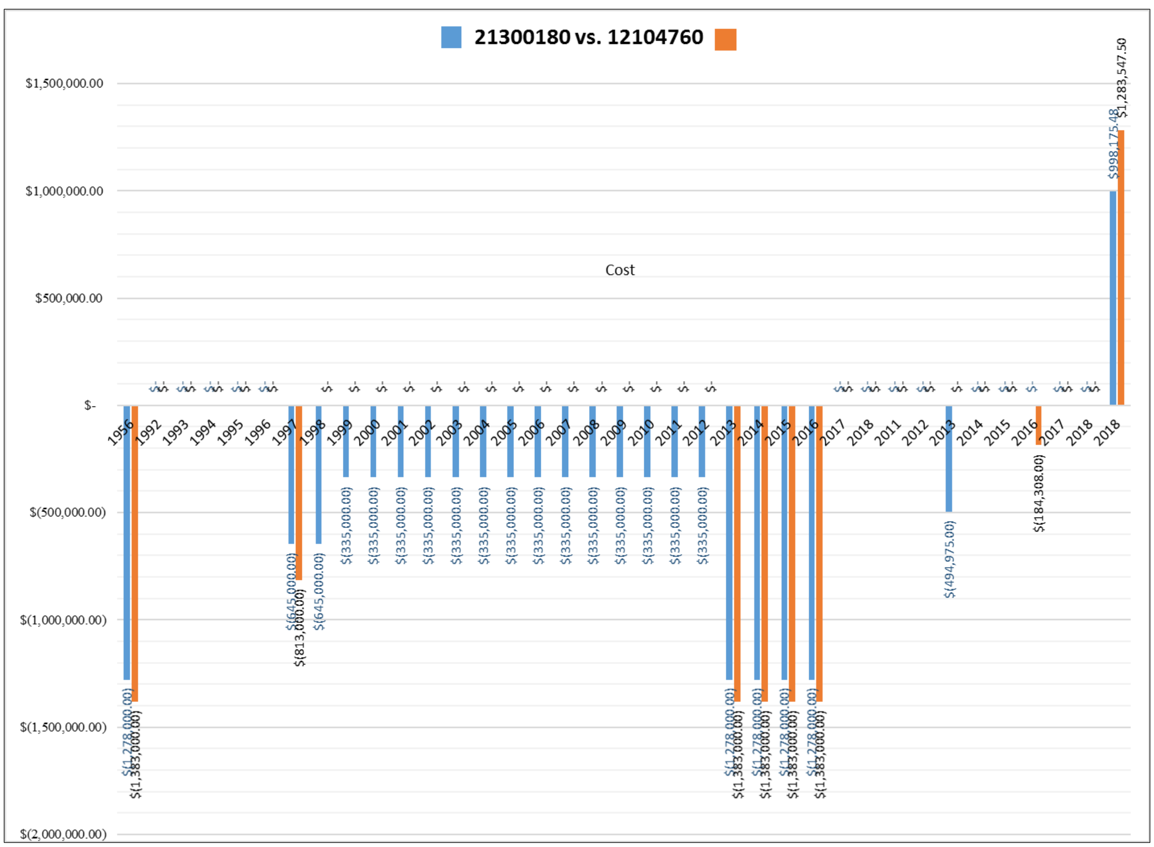

Figure 38 - Excerpt Cash Flow analysis of Selected Bridges.

The cash flow analysis tool is able to simply gather all maintenance, and historic costs of bridges. The macros, buttons, and drop down menus make it easy to search for the desired bridge ID number and create a bar chart to visualize the bridges rehabilitation expenses over its life.

4.3.1 *Benefit of Georgia's Bridges*

Benefit is the advantage, or profit gained from an object. Determining the benefit of the bridge is a way of putting a number on a particular bridge's worth. The benefit takes into account a particular bridges modified health index as well as the initial project cost. Ideally, the bridges benefit will be used to weigh against the cost through a benefit cost ratio, which can be used when comparing the benefit between two bridges. The benefit will also be used to compare, internally, to a bridges past maintenance costs. In this will way it will act as a gauge whether to repair or replace a structure.

For all of Georgia's bridges, a benefit equation was able to be computed, from the equation defined during the cash flow analysis process. To determine the worth, or profit of all of Georgia's bridge infrastructure, the calculated benefit from each bridge was summed. The benefits were able to be summed to determine the overall benefit of Georgia bridges, at a total of $8,905,731,188.17. This number serves as a reminder to Georgia engineers the effort that needs to continually be put into maintaining this number, as well as can be used when determining budgeting to be allotted to Georgia's bridges. The figure below expresses a histogram of the benefit, displaying the range of benefit values as well as the number of bridges associated with each of the values. A majority of bridges are at a benefit range of $200,000, however there is another spike in bridges at a value of $2,000,000 for around 1700 bridges. $200,000 is not a particularly high number when compared to the average cost of construction of bridges, at $615,332.93. This indicates more work needs to be done in rehabilitation to increase health index scores, and subsequently the benefits. The third spike in values, at around 1500 bridges is for $400,000. In general the total sum of benefit of Georgia's bridges is high, however the bridges individually have a moderate benefit, indicating more rehabilitation work needing to be done to Georgia's Bridges.

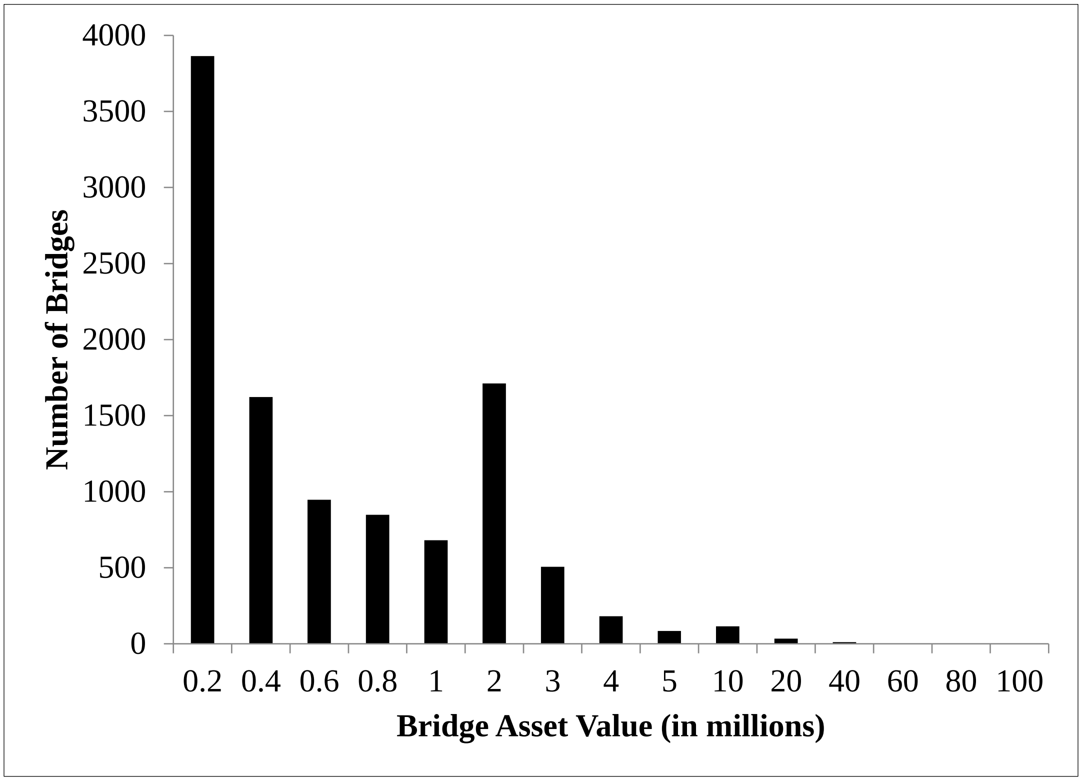

Figure 39 – Georgia Bridge Benefit MHI_{BR}.

4.3.2 *Replace vs. Repair Tool*

Using the compare bridges function and data from the cash flow analysis tool, a repair vs replace tool was able to be created to assist in decision making as well. The tool is designed to act as a future prediction instrument when deciding upon rehabilitation options. Because the values change and correspond with each individual bridge ID the analysis tool is able to be tailored to any bridge in Georgia. The tool prompts users to select a bridge and enter cost parameters for either repair or replacement. The outcome is a estimation of a bridges future occurrences if repair or replacement is chosen. For the replace option, selection of the bridge ID gathers maintenance costs, and makes these costs occur 8 years later than they actually do, after year 2019. The user is also able to input a replacement construction cost that acts as the new initial project cost. The repair option also prompts the user to enter the desired repair cost to occur in year 2019. Then, the previously occurred maintenance costs for the bridge occur starting after 2019. Future maintenance costs for the replacement option are delayed because a new bridge will not need maintenance soon, while a bridge that was repaired may require maintenance at a sooner time. This gives engineers an idea of the expenses and the benefit of each option when deciding between repair or replacement. The benefit cost ratio can also be determined by dividing the benefit by the sum of all maintenance costs.

Table 31 – Bridge 12101780 Replace vs Repair Analysis Tool

Replace	Year	Expenses	NPV Expenses
Present Value	2018	$ -	$ -
	2019	$ (3,000,000.00)	$ (1,002,082.99)
	2020	$ -	$ -
	2021	$ -	$ -
	2022	$ -	$ -
	2023	$ -	$ -
	2024	$ -	$ -
	2025	$ -	$ -
	2026	$ -	$ -
	2027	$ -	$ -
	2028	$ -	$ -
	2029	$ -	$ -
	2030	$ -	$ -
	2031	$ -	$ -
	2032	$ -	$ -
	2033	$ -	$ -
	2034	$ -	$ -
	2035	$ -	$ -
	2036	$ -	$ -
Maintenance Expenses	2037	$ -	$ -
	2038	$ -	$ -
	2039	$ -	$ -
	2040	$ -	$ -
	2041	$ -	$ -
	2042	$ -	$ -
	2043	$ -	$ -
	2044	$ -	$ -
	2045	$ (2,689,000.00)	$ (1,982,933.48)
	2046	$ -	$ -
	2047	$ (2,689,000.00)	$ (2,107,485.89)
	2048	$ (883,418.08)	$ (713,786.65)
	2049	$ (2,689,000.00)	$ (2,239,861.72)
	2050	$ -	$ -
	2051	$ (2,689,000.00)	$ (2,380,552.37)
	2052	$ -	$ -
	2053	$ -	$ -
	2054	$ -	$ -
	2055	$ -	$ -
Benefit	2055	$ 2,981,916.61	
Total NPV			$ (10,426,703.09)
Benefit Cost Ratio			0.29

Repair	Year	Expenses	NPV Expenses
Construction Cost	2018	$ (2,689,000.00)	$ (871,254.37)
	2019	$ (500,000.00)	$ (167,013.83)
	2020	$ -	$ -
	2021	$ -	$ -
	2022	$ -	$ -
	2023	$ -	$ -
	2024	$ -	$ -
	2025	$ -	$ -
	2026	$ -	$ -
	2027	$ -	$ -
	2028	$ -	$ -
	2029	$ -	$ -
	2030	$ -	$ -
	2031	$ -	$ -
	2032	$ -	$ -
	2033	$ -	$ -
	2034	$ -	$ -
	2035	$ -	$ -
	2036	$ -	$ -
Maintenance Expenses	2037	$ -	$ -
	2038	$ (2,689,000.00)	$ (1,602,176.23)
	2039	$ -	$ -
	2040	$ (2,689,000.00)	$ (1,702,812.45)
	2041	$ (883,418.08)	$ (576,727.37)
	2042	$ (2,689,000.00)	$ (1,809,769.85)
	2043	$ -	$ -
	2044	$ (2,689,000.00)	$ (1,923,445.47)
	2045	$ -	$ -
	2046	$ -	$ -
	2047	$ -	$ -
	2048	$ -	$ -
	2049	$ -	$ -
	2050	$ -	$ -
	2051	$ -	$ -
	2052	$ -	$ -
	2053	$ -	$ -
	2054	$ -	$ -
	2055	$ -	$ -
Benefit	2055	$ 2,672,791.26	
Total NPV			$ (8,653,199.57)
Benefit cost Ratio			0.31

For example, a replacement construction cost of $3,000,000 was entered and maintenance costs recorded from NBI and GDOT start to occur in year 2027 for bridge ID 12101780. The benefit is then taken from the new construction cost. For repair, an estimated repair cost of $500,000 was entered, while the initial project cost stayed the same. The benefit was then taken from the construction cost. This process for bridge 12101780 is shown in Table 31. Based upon the benefit cost ratio for each rehabilitation option, bridge 12101780 would better benefit from an investment of repair because of the higher ratio. The replace option has a benefit cost ratio of .29 while the Repair has a ratio of .31.

Table 32 – Bridge 12101780 original Maintenance Coat Data

	Year	Expenses	NPV Expenses	Interest Rate	Total NPV
Construction Cost	1962	$ (2,689,000.00)	$ (488,436.29)	0.03	$ (10,944,465.92)
NBI & GDOT	1992	$ -	$ -		
	1993	$ -	$ -		
	1994	$ -	$ -		
	1995	$ -	$ -		
	1996	$ -	$ -		
	1997	$ -	$ -		
	1998	$ -	$ -		
	1999	$ -	$ -		
	2000	$ -	$ -		
	2001	$ -	$ -		
	2002	$ -	$ -		
	2003	$ -	$ -		
	2004	$ -	$ -		
	2005	$ -	$ -		
	2006	$ -	$ -		
	2007	$ -	$ -		
	2008	$ -	$ -		
	2009	$ -	$ -		
	2010	$ -	$ -		
	2011	$ -	$ -		
	2011	$ -	$ -		
	2012	$ -	$ -		
	2012	$ -	$ -		
	2013	$ (2,689,000.00)	$ (2,309,135.80)		
	2013	$ -	$ -		
	2014	$ (2,689,000.00)	$ (2,380,552.37)		
	2014	$ (883,418.08)	$ (782,083.67)		
	2015	$ (2,689,000.00)	$ (2,454,177.70)		
	2015	$ -	$ -		
	2016	$ (2,689,000.00)	$ (2,530,080.10)		
	2016	$ -	$ -		
	2017	$ -	$ -		
	2017	$ -	$ -		
	2018	$ -	$ -		
	2018		$ -		
Benefit	Current	$ 2,672,791.26	$ 2,672,791.26		

5. DISCUSSION AND FUTURE WORK

The study was able to assign a monetary value to Georgia's bridges, as well as update engineers on their bridges actual health. The tools created through this study will be able to serve Georgia's engineers in the future, by progressively keeping track of bridge health and making rehabilitation based decisions. Thought out decisions on repair or replacement are able to better be made through the updated bridge health measures.

The asset valuation was able to use preferences made from the conjoint analysis to modify the health index values. The health index is the main component used by GDOT engineers when assessing bridge value and determining if a bridge needs some form of rehabilitation, including repair or replacement. Using fact-based preferences to better alter the health index has resulted in a modified health index value that can be relied upon to represent the bridge. The new modified health indexes, MHI_{BR}, concludes that a majority of Georgia's brides are in good condition. A majority of health index values reside from ranges 60 to 100. Georgia engineers determine bridge ranges from 60 to 70 to be in good condition, while above 70 to be in excellent condition. While overall a majority of bridges are considered to be in good condition, there is a significant number that do need to be repaired. There is a spike in bridges in poor condition at the health index value range of 48 to 50. The MHI_{BR} are also more precise, with at least 4 decimal points. This allows for more differentiation when categorizing bridges into groups of good or excellent. This variation allows for easier decision making when concluding between similar bridges, with similar issues.

The cash flow analysis tool is also able to build upon the idea of deciding between two different bridges. The tool is able to gather all documented maintenance costs, historic costs, and benefit for bridges selected to compare. The gathered data is then visually represented in a bar chart. Engineers will be able to view the chart, or the gathered excel data, and decide upon which bridge it is most beneficial to repair or be replaced based upon benefit to cost ratios or which bridge has benefited from maintenance most in the past.

The future work can include expanding upon the cash flow analysis tool and element cost database. It is suggested that the cash flow analysis tool be expanded to include an operation that is able to compare elements, by paralleling the depreciation rates to assist when determining what element to use during replacement. It is also suggested that the element cost database be continued to be expanded upon, as that collection of data would be an asset.

6. CONCLUSIONS AND RECOMANDTIONS

The result of this study is the analysis of Georgia's bridge expenses over their lifetimes. Cost figures such as maintenance costs, historical costs, and unit costs were vital in the study. Analysis techniques included asset valuation as well as a conjoint analysis. The conjoint analysis allows for engineers to correct health index values by surveying preferences on important factors causing poor performance of Georgia's bridges. In terms of asset valuation, a unit cost database and cash flow analysis were used to assign monetary value to bridges. The unit cost database established costs for individual bridge elements over a span of years that is able to help determine the cost of future bridge repair or replacement. The cash flow analysis uses a simple method of displaying historic cost, maintenance cost, and a current benefit cost that assists in making rehabilitation decisions.

Regression techniques were used to turn engineer preferences into representative values of those preferences, attribute-worths. The attribute-worths were applied to health indexes to reflect their value. The altered value is more indicative of actual health and will assist inspectors and engineers in better choosing bridges that need repair. The attribute-worths represented the age, region, and presence of waterway. These factors were determined to affect bridges but cannot be represented during inspections and subsequently measuring the health index. Results also show more variation is health index values. Meaning, the decimal point and integers allow for more differentiation between bridge ID's.

The element cost database created a large collection of element costs over a variety of years. The unit costs can be anticipated to determine, approximate, future total bridge constructions costs, as well as individual element replacement costs. This system was necessary to assist GDOT engineers in deciding between repair or replacement options, and also deciding between repair or replacement for multiple bridges. The results show a trend in prices and also allow for the possibility of predicting future unit cost prices by tracking trends.

The cost-benefit analysis tool with a cash flow diagram gathers cost figures of all of Georgia's documented bridges and puts them in one accessible place. Previously, historic costs and maintenance costs were found in different databases such as the National Bridge Inventory and maintenance costs personally collected by Georgia engineers. The cash flow analysis also states the benefit of the bridge, or the current worth a bridge is valued in relation to its health index and historic cost. The results show that many of the bridges have multiple expensive, repetitive maintenance costs with not much representative change in the health index value. Engineers will be able to analyze the cash flow analysis and come to a conclusion about future rehabilitation operations. The cash flow analysis is also able to offer suggestions on repair or replacement of bridges. It gathers bridges with the health index, predicts future maintenance costs, and comes to the conclusion whether a bridge should be repaired or replaces. The cash flow analysis tool will be able to act as a decision making too.

The issue brought to hand by GDOT is the need to better track bridge progress and spending. Currently GDOT engineers update the NBI database with maintenance information from the Maintenance Unit. They also track maintenance on bridges in their own excel spreadsheet. With the help of this research study engineers will be able to better track bridge health, be more aware of bridge condition, and make decisions more easily.

It is recommended that GDOT engineers incorporate the results of this study into their daily routine. Implementation of the conjoint analysis can be used in the future by constantly updating health indexes within the excel sheet after current inspections. Atrribute-worths will automatically be applied to new health indexes to always produce the most accurate bridge health index. Within the cash flow analysis the bridge health index will be updated after inspections and the attribute-worths are applied. Once health indexes are updated, it is recommended the cash flow analysis be used when reviewing all expenses of a bridge or comparing two bridges in terms of costs. It is finally recommended that the element unit cost database be used to approximate bridge maintenance costs. It can be improved and used when determining rehabilitation processes as a cost-benefit analysis tool.

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