ADVANCING BRIDGE LOAD RATING AND E-CONSTRUCTION TECHNOLOGIES FOR TRANSPORTATION AGENCIES

by

LAUREN J. SHANNON

(Under the Direction of Stephan A. Durham)

ABSTRACT

Transportation agencies are constantly seeking new methods for engineering, construction, and administration in order to improve project efficiency and quality. The Georgia Department of Transportation (GDOT) is interested in upgrading its bridge load-rating software to use the Load and Resistance Factor Rating (LRFR) method, incorporating field-measured deterioration and bridge substructure. This study investigates a load-rating approach using finite element modeling with influence surface areas. A sensitivity analysis was conducted to determine the effect of existing section loss of bridge elements. In addition to bridge load rating, GDOT seeks to improve its administrative processes. The department's e-Construction initiative includes electronic submission and distribution of all construction documentation. By updating its e-Construction program, GDOT hopes to increase efficiency throughout the entire life cycle of state projects with improved communication, document tracking, and transparency. This study identifies the limitations of GDOT's current construction administration processes and establishes an implementation framework for department-wide improvements.

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# 1.0 INTRODUCTION

## 1.1 | Background

State departments of transportation (DOTs) are constantly seeking new methods for engineering, construction, and administration in order to improve project efficiency and quality. The Georgia Department of Transportation (GDOT) is interested in improving two processes in particular, the first being bridge load rating. GDOT currently employs a load rating program that analyzes bridge structures based on the Load Factor Rating (LFR) method. Timber components are the only bridge members that are not rated based on this method and are analyzed using a service load approach. According to a 2014 survey conducted by the National Cooperative Highway Research Program (NCHRP), GDOT recognizes the value in utilizing field-measured section loss when evaluating deterioration of bridge members. Based on critical findings, state bridge inspectors may recommend or request a load rating to be re-evaluated [Hearn, 2014]. Currently, bridge superstructure is the primary focus throughout GDOT's load rating process. GDOT would like to upgrade its bridge load rating software to have the capability of incorporating field-measured deterioration and bridge substructure for more accurate results.

In addition to bridge load rating, GDOT seeks to improve its e-Construction program. The Federal Highway Administration (FHWA) introduced the Every Day Counts Initiative in 2015 to implement new design and construction methods as well as administrative innovations with the purpose of reducing project delivery time, enhancing safety, and protecting the environment [FHWA, 2016]. One of these FHWA innovations is e-Construction, a paperless construction administration method. E-Construction includes electronic submission and distribution of all construction documentation as well as electronic document approvals and signatures. The traditional paper-based system used today by most DOTs requires extensive documentation, which involves postal delivery, hand note-taking, stamped plan sets, design and construction submittals, and physical signatures on multiple copies of several documents. The e-Construction initiative aims to improve the construction management process by employing document technologies available on mobile devices. The FHWA believes e-Construction will save money by decreasing paper usage, printing, and document storage. In addition, it will eliminate communication delays and extended transmittal times, which translates to more savings. This management method improves communication among all parties involved with a DOT construction project. Electronic submissions and approvals allow for enhanced document tracking and transparency [FHWA, 2017]. By updating its e-Construction program, GDOT hopes to increase efficiency throughout the entire life cycle of state projects.

# 2.0 PROBLEM STATEMENT

## 2.1 | Research Significance

The Georgia Department of Transportation has identified several limitations with its current load rating program. The GDOT Bridge Design and Maintenance Office is interested in replacing the current program with one that is more robust and able to account for actual field conditions. GDOT expects that the new program will have capabilities to analyze bridge decks, superstructures, and substructures using the service load approach, including both the LFR method and the Load and Resistance Factor Rating (LRFR) method. In order to determine the most appropriate solution, extensive research of state load rating practices and available load rating software was necessary. The focus of Phase I of this research was to recommend a plan for advancing GDOT’s load rating procedures for bridge superstructure in particular.

Phase II of this research was aimed at improving GDOT’s e-Construction program. On September 1, 2016, the Federal Highway Administration published a new Notice of Funding Opportunity for the Accelerated Innovation Deployment (AID) Demonstration. The AID Demonstration is authorized under the Fixing America’s Surface Transportation (FAST) Act, which continued the Technology and Innovation Deployment Program (TIDP). The purpose of the AID Demonstration was to provide incentive funding for qualified highway transportation projects in order to compensate for the risk of implementing an innovation. The FHWA plans to provide $10 million worth of funding each fiscal year from 2016 to 2020, with approximately $9 million going to state departments of transportation. The Georgia Department of Transportation is interested in applying for funding to implement more advanced e-Construction initiatives beginning in October of 2018. To GDOT’s advantage, e-Construction is one of the innovations encouraged by the FHWA as a part of its Every Day Counts Initiative [FHWA, 2016]. Phase II of this study assisted GDOT with creating a proposal for AID Demonstration funding.

**2.2 | Research Objectives**

The primary objective of Phase I of this research was to develop a proof of concept for a bridge load rating method using ANSYS Workbench 18.2 in relation to the outcomes desired by the Georgia Department of Transportation. The selected program was used to perform an elemental bridge load rating analysis of a GDOT Bridge (ID 059-5015-0) located in Athens, Georgia. Portions of the bridge superstructure were modeled in the software based on original section properties, material properties, and boundary conditions. In order to validate the analytical model, vibration testing was conducted on the bridge and compared to a modal analysis from the software. Unit loading was then applied to the model in various vehicle configurations using the influence surface area method. The load rating procedure was then investigated in terms of GDOT's software expectations as well as the accuracy of the results it provided. The overall goal of this project was to facilitate the development of a framework for advancing GDOT's bridge loading rating procedure.

The objective of Phase II was to identify the current limitations of GDOT's construction administration processes and to establish an implementation framework for a more advanced, department-wide e-Construction program. The end goal was to develop a proposal for the FHWA AID Demonstration with the hopes of acquiring federal funds to transition to complete paperless communication and document transfer. Prior to developing the AID proposal, departmental coordination was identified and other state DOT e-Construction practices were reviewed.

# 3.0 LITERATURE REVIEW

## 3.1 | Overview

This literature review examines the current methods and procedures for state bridge load rating and load posting. It discusses analytical and experimental methods as well as modeling with available load rating software. In addition, this review covers background information regarding the FHWA AID Demonstration and the implementation of e-Construction by state DOTs. Furthermore, it discusses both benefits and challenges other departments have encountered with e-Construction innovations.

## 3.2 | Bridge Load Rating

This section of the literature review discusses load rating methods, bridge load posting, state DOT load rating software usage, diagnostic load testing, and finite element bridge modeling.

### 3.2.1 | Load Rating Methods

Load rating is a measure of bridge live load capacity based on two categories: inventory rating and operating rating. Inventory rating includes loads in multiple lanes that can safely utilize the bridge for an indefinite period of time. Operating rating is the maximum permissible live load that can be placed on the bridge [Freeby, 2013]. Three load rating methods typically used for bridges include Allowable Stress Rating (ASR), Load Factor Rating (LFR), and Load and Resistance Factor Rating (LRFR). The loads that are considered for rating include American Association of State Highway and Transportation Officials (AASHTO) HS-20 loading, AASHTO Type 3, 3S2 and 3-3 loading, and state-specific legal loads [Hearn, 2014].

Allowable Stress Rating compares the maximum stresses produced by the actual loading to the structural member's allowable stress. This method treats live loads and dead loads equally. It is difficult to assign an ultimate strength to timber, therefore, ASR is commonly used for timber bridges and any bridges that cannot be rated by other methods [Freeby, 2013]. The ASR rating factor (RF) equation, according to the AASHTO Manual for Bridge Evaluation (MBE), is shown below in Eq. 1.

$$RF = \frac{C - A_1 D}{A_2 L(1+I)}$$ **Eq. 1 [Kaskas, 2014]**

Where:

$C$ = capacity of the rated member

$D$ = dead load on the member

$L$ = live load on the member

$I$ = impact factor

$A_1$ = factor for dead loads ($A_1 = 1$ for ASR)

$A_2$ = factor for live loads ($A_2 = 1$ for ASR)

Load Factor Rating is based on applying different load factors to each load type and comparing the effects of the factored loads to the strength of the load carrying members. LFR is a strength based method with no guidance on adjusting load and resistance factors. LFR is commonly used on existing bridges and minor rehabilitations or repair bridges. Equation 1 is used to calculate the rating factor for the LFR method, however, $A_1$ and $A_2$ are no longer equal to one [Kaskas, 2014].

Load and Resistance Factor Rating provides a single safe load capacity for indefinite use. This method has uniform reliability and involves probabilistic methods to derive load and resistance factors. This method is based on finite element analysis (FEA). LRFR consists of three different evaluations: design-load rating, legal-load rating, and permit-load rating. U.S. DOT policy requires states to report load ratings using the LRFR basis for structures designed or replaced after October 1, 2010 [Hearn, 2014]. The rating factor equation for the LRFR method is shown in Eq. 2.

$$RF = \frac{C-\gamma_{DC}(DC)-\gamma_{DW}(DW)}{\gamma_L(LL+IM)}$$ **Eq. 2 [Kaskas, 2014]**

Where:

$C = \phi_s \phi_c \phi R_n$, where $\phi_s$ is the system factor, $\phi_c$ is the condition factor, and $R_n$ is the calculated nominal member resistance

$\gamma_{DC}$ = LRFD load factor for structural components and attachments

$DC$ = dead load effect due to structural components and attachments

$\gamma_{DW}$ = LRFD factor for wearing surfaces and utilities

$DW$ = dead load effect due to wearing surface and utilities

$\gamma_L$ = evaluation live load factor

$LL$ = live load effect

$IM$ = dynamic load allowance

This equation does not consider permanent loads other than dead loads. The condition factor accounts for the uncertainty in the resistance of deteriorated members or future deterioration. This factor is 1.00 for a good or satisfactory structure, 0.95 for a fair structure, and 0.85 for a poor structure. The system factor relates to the redundancy of the superstructure. Bridges with non-redundant configurations are required a higher safety level. The dead and live load factors used in the equation are specified in the AASHTO MBE.

Load and resistance factor ratings are calculated at each limit state, and the load effect with the lowest value determines the controlling rating factor. Limit states include Strength I, Strength II, Service I, Service II, and Fatigue. A rating factor less than one identifies a vulnerable bridge that should be evaluated for the posting needs. Design-load rating assess the vulnerability of bridges based on the HL-93 live loading from the LRFD Specifications. HL-93 loading consists of a design truck or tandem plus a design lane load. The design truck is the same as the HS-20 load configuration, a 20 ton two-axle truck with the front axle carrying 8,000 pounds and the rear axle (14 feet away) carrying 32,000 pounds. The design tandem carries an axle load of 25,000 load [Munkelt, 2010].

### 3.2.2 | Bridge Load Posting

Published by the Transportation Research Board (TRB) in 2014, National Cooperative Highway Research Program Synthesis 453 discusses state government processes and practices for bridge load rating. Under federal regulation, state governments identify highway bridges and culverts to post for load, evaluate safe load capacities of these structures, and implement vehicle weight restrictions. Bridge load rating accounts for current conditions that alter its strength or loading. Structures are posted for load when safe load capacity is less than the specified legal loads. Periodic safety inspections determine when it is necessary to update load ratings. In some cases, states may exempt some vehicles or issue overweight permits for certain structures.

The federal National Bridge Inventory (NBI) contains information on public bridges and culverts with a span greater than 20 feet. The information includes structure type, location, condition, year built, structure owner, route, average daily traffic, load rating values, rating methods, and load posting status. Table 1 provides a summary of the current status of load posted bridges in the United States. Forty-eight percent of load posted structures are structurally deficient, and 17% are functionally obsolete. About 37% of steel stringer/multi-beam or girder bridges are load posted structures, making it the most frequently load posted structure. In addition, 51% of wood or timber stringer/multi-beam or girder bridges are load posted.

**Table 1—Summary of Load Posted Bridges in the U.S. [Hearn, 2014]**

| Category | Description |
| --- | --- |
| *Prevalence* | 10% of U.S. bridges and culverts are posted for load. |
| *Owner* | 80% of load posted structures are owned by local governments. In most states, less than 1% of state-owned structures are posted for load. |
| *Route System* | 91% of load posted structures are on rural roads, 76% are on low-volume roads, and 79% carry fewer than 20 trucks per day. Less than 1% of structures on interstate routes are posted for load. |
| *Condition* | 75% of load posted structures are in fair or good condition. |
| *Age* | 88% of load posted structures were built before 1980. Less than 2% of structures built after the year 2000 are posted for load. |
| *Design Load* | 77% of load posted structures have unknown design live load or were designed for live load equal to or less than H-15 loading. |
| *Structure Type* | 95% of load posted structures are bridges. Among all bridges, 12% are posted for load. Among all culverts, 2% are posted for load. |
| *Load Rating Method* | 93% of load posted structures have load ratings determined by computational methods. 7% have load ratings determined by field evaluation and engineering judgment or without load rating analysis. Load tests are used for less than 1% of load ratings. |

NCHRP conducted a survey of states on load posting practices, state statutes, state administrative codes, and Department of Transportation (DOT) publications. In most states, authority to post state-owned bridges and culverts for load is held in the DOT central office by the state bridge load rater, state bridge engineer, DOT chief engineer, or DOT director. In other states, the DOT only takes responsibility if the local government fails to implement posting when necessary. In either case, the federal government requires states to ensure that all bridges and culverts are inspected and load posted if necessary. States are not responsible for structures owned by the federal government. Most states have DOT staff that complete evaluations of load ratings, but others use engineering consultants and perform review of their work. The Georgia Department of Transportation (GDOT) performs safety inspections of all structures on public roads that are owned by state or local government. GDOT does not inspect structures on privately owned roads. However, the Georgia DOT provides local governments with findings from inspections and recommendations for maintenance or posting.

Safety inspections provide quantitative data that reveals any changes to bridges or culverts that might affect its load capacity. DOT load rating engineers review inspection reports and re-evaluate load ratings as needed. The most common NBI general condition rating (GCR) value to prompt re-rating is 4 out of 9. Bridge databases must be updated within 90 days for state-owned structures and within 180 days for local government structures if a load rating or posting status changes. The time interval from an initial recommendation to consider load posting to the installation and verification of weight limit signs ranges from less than one week to more than one year. States peer review load rating computations, review computer models, and complete hand computations to verify software outputs.

Federal regulation of loads applies to interstate highways, while state law applies to other highways. Local law applies to roads owned by local governments. Load limits for highway bridges and culverts are expressed as limits on axle loads, on tandem axle loads, and vehicle gross weights. The general limits are 20,000 lbs for single-axle load, 34,000 lbs for tandem-axle load, and 80,000 lbs for gross vehicle weight (GVW). The majority of states enforce these same limits. Vehicles that exceed the federal or state limits include vehicles protected by grandfather provisions according to federal regulation, longer combination vehicles named as exceptions, vehicles exempt from state law for specific commodities or specific uses, and vehicles that qualify for overweight permits.

Two levels of load rating are reported to NBI: inventory rating and operating rating. The inventory rating is a lower bound on the safe load capacity of a structure. The operating rating is the maximum tolerable load for a structure. Load ratings are computed as design load ratings, legal load ratings, and overweight permit vehicle ratings based on rating vehicles. A rating vehicle is a defined set of axle weights and axle spacing. Load posting may be set at a structure's operating rating, its inventory rating, or at a level in between.

All states use computational structural analysis to determine load ratings. The most common approach is approximate structural analysis using live load distribution factors. Three-dimensional models are used for complex bridges and structures that are expected to require load posting due to observed deterioration. Load rating computation is based on Allowable Stress Rating (ASR), Load Factor Rating (LFR), or Load and Resistance Factor Rating (LRFR). A rating factor is a scaling factor describing a structure's capacity in relation to a rating vehicle. A rating factor greater than 1 means it has a capacity higher than the load of a rating vehicle. Diagnostic load tests are often used in structure load rating. Field evaluation and engineering judgement is used when computational load rating is not possible.

As previously mentioned, U.S. DOT policy requires states to report load ratings using the LRFR basis for structures designed or replaced after October 1, 2010. For other structures, load ratings may be reported using the LRFR or LFR method. Load ratings for timber bridges and masonry bridges may be reported using the ASR method. All states included in the NCHRP survey use beam line analysis in load rating computations. Twenty-four states use refined analysis methods for some load rating computations. AASHTO recommends the use of refined analysis in place of beam line analysis when beam line analysis yields a low load rating.

Specific weight limits for posted structures can depend on structure condition, average daily traffic, detour length, load path redundancy, and the level of enforcement of weight limits. Superstructure components are always included in load rating evaluations. Sometimes bridge decks and substructure components are included, depending on the condition of the bridge. Most states use AASHTO vehicles in load rating, and deterioration of components are taken into account with AASHTO's condition factor. Remaining strength of components may be based on field-measured dimensions or diagnostic testing.

Current research related to load posting includes the use of weigh-in-motion (WIM) data to characterize truck loads and to evaluate multiple presence factors, calibration of refined models for structural analysis, development of load rating methods for complex bridges, and evaluation of load effects of special vehicles on bridges [Hearn, 2014].

### 3.2.3 | State DOT Load Rating Software

According to NCHRP Synthesis 453, only eight states currently evaluate bridge substructure in addition to superstructure: California, Georgia, Kentucky, Louisiana, Mississippi, Nevada, North Carolina, and Tennessee. These states inspect bridge substructure for signs of deterioration, such as cracking, section loss, settlement, misalignment, scour, collision damage, and corrosion [Hearn, 2014]. In addition to the survey conducted by the NCHRP, state bridge manuals provide valuable information regarding load rating procedures. These manuals were used to determine the most popular load rating software used by state DOTs. The most commonly used programs include AASHTOWare Bridge Rating (BrR), BRASS, and in-house software. Some states indicate that load ratings for complex bridges are typically analyzed by 3-D finite element models or other complex methods. A summary of the load rating software used by state DOTs is shown in Figure 1 and Table 2. This summary includes multiple software programs per state and excludes the following states: Alaska, Arkansas, California, Delaware, Hawaii, Idaho, Missouri, New Hampshire, Oklahoma, South Carolina, South Dakota, Tennessee, Vermont, and West Virginia. Manuals for these states were not located.

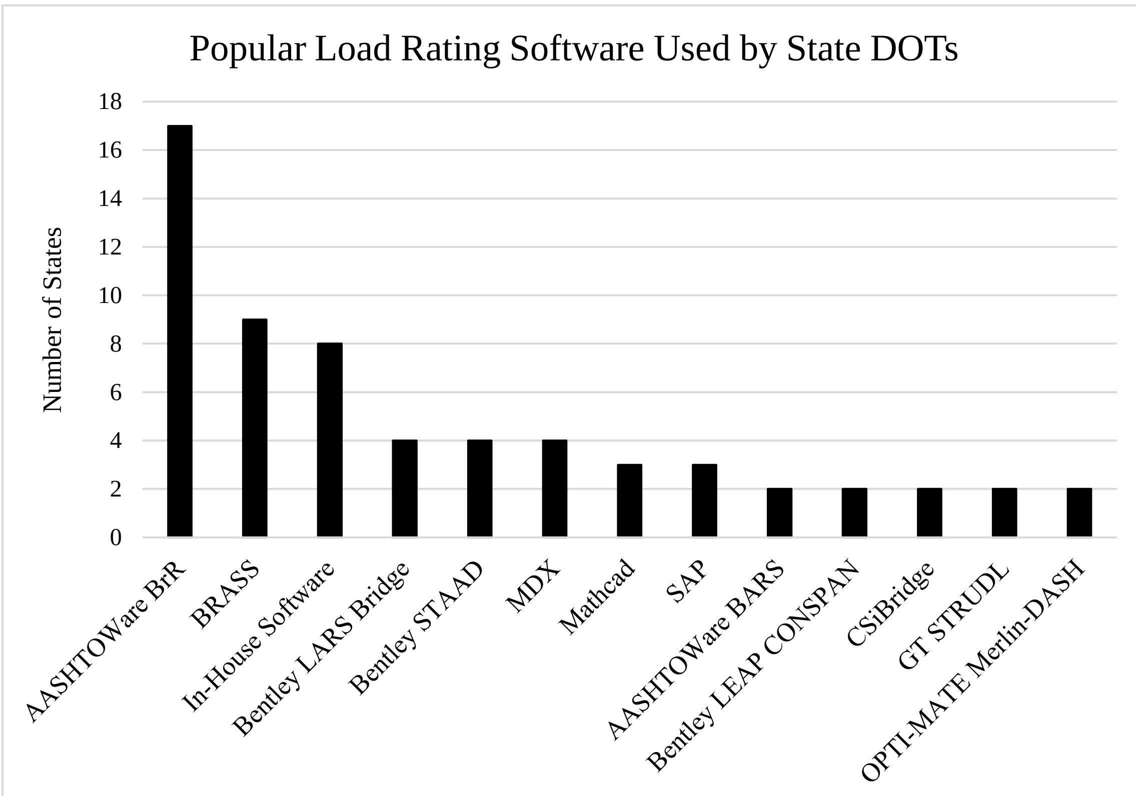


**Figure 1—Popular Load Rating Software Used by State DOTs**

**Table 2—Load Rating Software Used by State DOTs**

| Software | Number of States | States |
|---|---|---|
| AASHTOWare BrR | 17 | AL, AZ, IA, IL, IN, KS, LA, MA, MI, MN, MS, MT, NE, NM, NY, UT, VA |
| BRASS | 9 | AL, NC, NM, NV OH, OR, RI, UT, WY |
| In-House Software | 8 | CO, GA, IA, ME, PA, TX, WA, WI |
| Bentley LARS Bridge | 4 | IL, IA, KY, NJ |
| Bentley STAAD | 4 | CT, IL, OH, PA |
| MDX | 4 | AZ, ME, NV, RI |
| Mathcad | 3 | CT, FL, ME |
| SAP | 3 | NV, OH, RI |
| AASHTOWare BARS | 2 | IN, OH |
| Bentley LEAP CONSPAN | 2 | AZ, FL |
| CSiBridge | 2 | IN, UT |
| GT STRUDL | 2 | AZ, OH |
| OPTI-MATE Merlin-DASH | 2 | AL, OH |
| AASHTOWare BDS | 1 | AZ |
| Bentley LEAP CONBOX | 1 | AZ |
| Bentley LEAP CONSPLICE | 1 | IN |
| Bridge Designer II (BD2) | 1 | NV |
| BRUFEM | 1 | AL |
| C-Bridge | 1 | CT |
| Complex Truss | 1 | KY |
| Culvert Analysis and Design (CANDE) | 1 | IN |
| Microsoft Access | 1 | CT |
| MIDAS | 1 | IN |
| OPTI-MATE DESCUS | 1 | VA |
| PENNDOT BAR7 | 1 | CT |
| PENNDOT BOX 5 | 1 | CT |
| PENNDOT PS3 | 1 | CT |
| SIMON | 1 | AZ |
| SmartCulvert | 1 | IN |
| TRC WinBDS | 1 | NV |

### 3.2.4 | Diagnostic Load Testing

The analytical load rating approach outlined by AASHTO requires assumptions about the support condition of the components being rated as well as design drawings. When this information is not available, diagnostic load testing can be used to understand the behavior of a bridge or its components subjected to a known load. The relationship between the load and the response can be used to confirm or deny assumptions in question. The testing is usually conducted with strain gauges, and the response is typically measured as strain and deformation at critical locations. These results can then be used to establish improved models for load rating.

When posted bridges are tested, they often show strength and stiffness capabilities beyond what was calculated through load rating procedures. This is due to the fact that theoretical load rating approaches are very conservative. According to one study that tested a bridge with strain transducers, the critical rating factor from the physical testing was 42% higher than the calculated rating factor. The authors found the physical testing method to be more accurate [Pharres et al., 2003]. Additionally, Fu et al. [2] used strain gauges to determine the maximum stresses in the webs and nominal section moduli of the beams on a steel highway bridge. They concluded that the load distribution factors of some beams were determined to be reasonably close to but lower than the analytical AASHTO values. The load test verified the reserved strength of the beams that was not taken into account in the original analytical rating. This explains why the applied load induced only about half the stress predicted analytically.

The three steps of diagnostic load testing are preparation, execution, and analysis of results. An inspection is conducted as part of the preparation stage in order to identify sources of reserve strength, identify and assess deterioration, and estimate the probability of success in improving the analytical rating with diagnostic load testing. Strain gauges can be used on beam bottom flanges to evaluate support-fixity, on beam webs and bottom flanges at the mid-span to measure bending strains and moment, and on box-beam rails to evaluate their participation in load sharing. The cost of the load testing is often less expensive than strengthening the bridge [Fu et al., 2014].

### 3.2.5 | Bridge Modeling

The approximate solution of a mathematical bridge model is reached by dividing the structure into regions of interest. Oftentimes the bridge superstructure and substructure are analyzed separately unless they were constructed integrally. The most common analysis method is the live load distribution factor method using 2013 AASHTO distribution factors. This approach is conservative and less accurate than refined analysis methods. Refined analysis methods include grillage analysis, the orthotropic plate method, the articulated plate method, finite strip method, and finite element method. Finite element analysis is useful for failure analysis of bridge structures.

Using the finite element method, a structure can be modeled using 1D, 2D, or 3D elements. Line elements used to model bridge members can be a bar element or a beam element. A bar element only has axial tension or compression with one degree of freedom at each node. This type of element is usually used to model a truss member, a bearing, or an individual member of a cross-frame. A beam element has six degrees of freedom and is usually used to model a beam or column with axial and bending stiffness. A grillage model adds torsion as another degree of freedom. Torsion may be significant for bridges that are highly skewed or have a long overhang. Grillage elements account for vertical translation, vertical flexural rotation, and axial torsional rotation. Figure 2 shows the degrees of freedom of a 3D frame element.

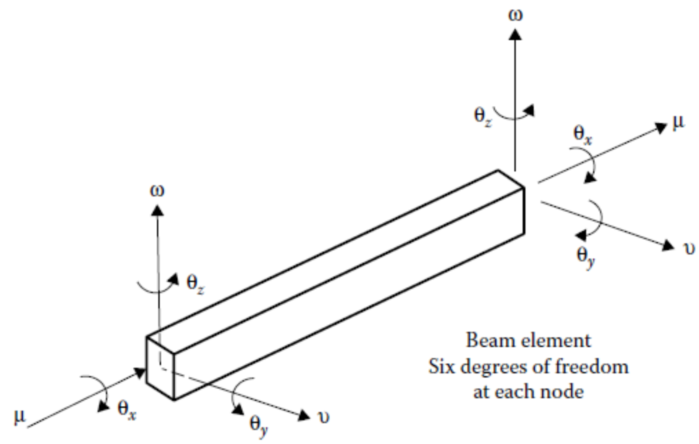


**Figure 2—Beam Element [Fu et al., 2015]**

Area elements are classified as either a membrane element or a plane shell element. A membrane element simulates only in-plane stress or strain. Each node of a membrane element has two degrees of freedom. A plane shell element simulates in-plane effects as well as plate bending. When applied in bridge analysis, each node of a plane shell element has five degrees of freedom as shown in Figure 3. These elements may be rectangular or triangular in shape.

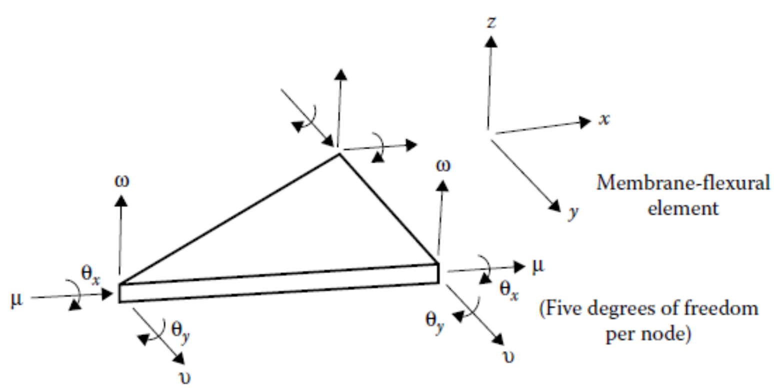


**Figure 3—Plane Shell Element [Fu et al., 2015]**

Volume elements, also known as solid elements, are another type of element used in FEA. As shown in Figure 4, these elements have three, four, eight, or more nodes built up from line or area elements. It is typical for a slab-beam bridge to be composed of area elements with a thickness equal to the slab thickness. Plane shell elements are used for both the web and flange of the beams

[Fu et al., 2015]. When discretizing a structure, it is important to avoid creating elements with high aspect ratios. The aspect ratio of an element is the ratio between its largest and smallest dimension. It is recommended to use elements with an aspect ratio less than or equal to three.

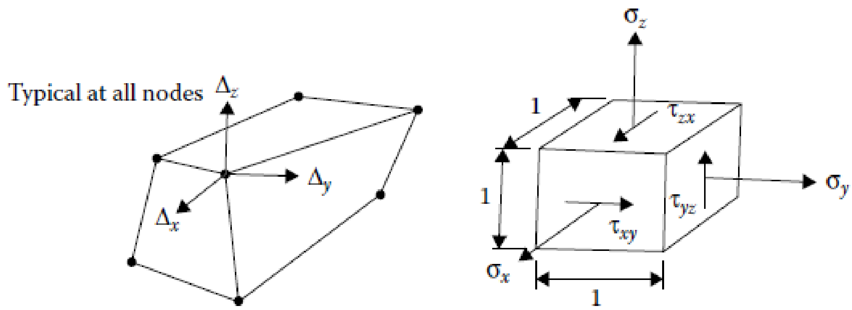


**Figure 4—Volume Element [Fu et al., 2015]**

### 3.2.5.1 | Influence Surface Loading

Influence lines and surfaces are commonly used in structural modeling to determine worst-case locations of live loads. An influence line shows the value of shear, moment, or other quantity at a specific location as a unit load travels over the structure [Cifuentes et al., 1991]. An influence surface follows the same concept in two dimensions with x and y surface coordinates and z as the ordinate. These surfaces directly project the ordinates of concentrated wheel loads. Influence surfaces can be modeled using FEA software and are particularly useful for bridge structures with irregular shapes [Fu et al., 2015].

### 3.3 | E-Construction

This section of the literature review provides background information regarding the FHWA AID Demonstration program as well as the benefits and challenges state DOTs have faced with implementing e-Construction innovations.

### 3.3.1 | FHWA AID Demonstration

Since September 2014, the AID Demonstration program has provided 69 awards with a sum of $47,870,115. The program has funded innovations such as 3D modeling, geospatial data collaboration, geosynthetic reinforced soil-integrated bridge systems, high friction surface treatments, intelligent compaction, prefabricated bridge elements, slide-in bridge construction, structural health monitoring, and work zone safety [FHWA, 2017]. Figure 5 shows the locations of agencies that have received funding through the AID Demonstration. Figure 6 shows the total dollar amount of funding over time. These agencies include state departments of transportation, federal land management agencies, and tribal governments. The Georgia Department of Transportation has not received funding through this program.

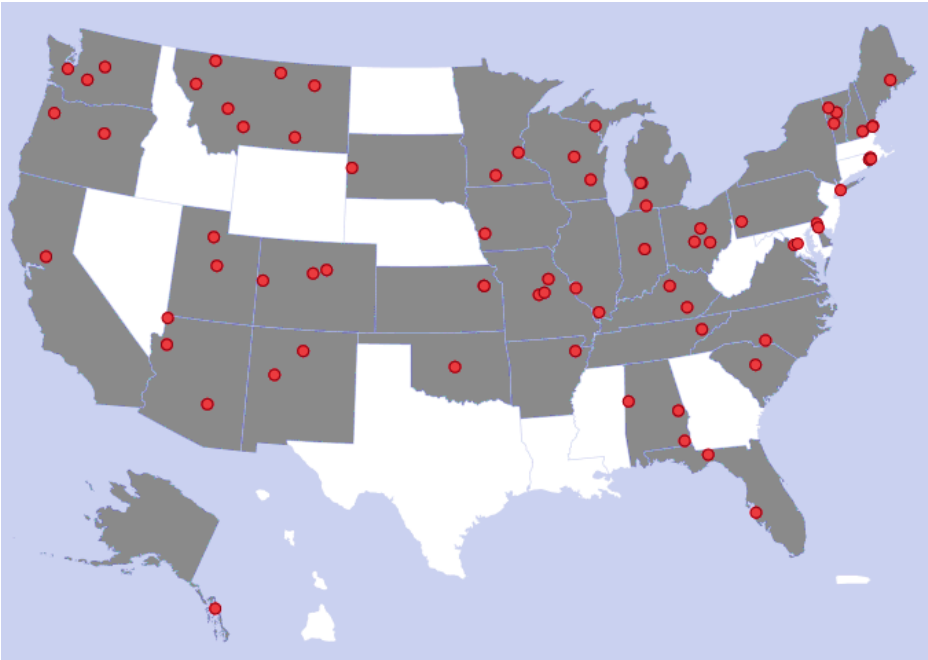

**Figure 5—AID Demonstration Project Locations [FHWA, 2017]**

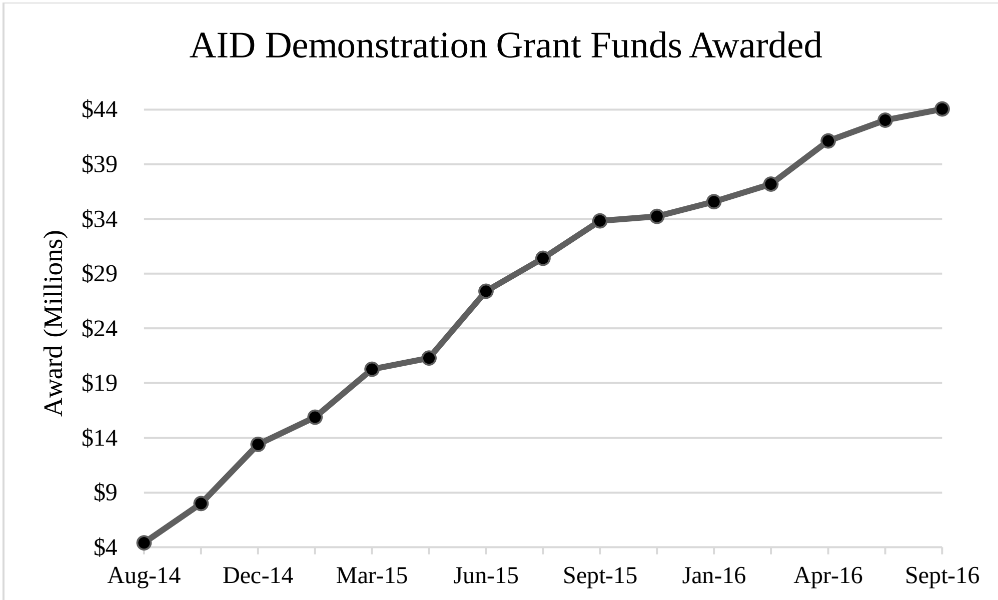


**Figure 6—AID Demonstration Grant Funds Awarded [FHWA, 2017]**

The AID Demonstration award is based on the cost of the innovation in a project, not the total cost of a project. The full cost of the innovation may be rewarded, but the maximum award is $1 million. The funds are available at an 80 percent federal share and require a minimum 20 percent cost share [Thompson, 2016]. The Kansas Department of Transportation (KDOT), Ohio Department of Transportation (ODOT), and Utah Department of Transportation have all received funding for the e-Construction innovation. KDOT received the maximum $1,000,000 in 2015 for updating its construction management system using electronic processes. ODOT received $511,762 in 2015 to improve document management and workflow throughout the design and construction of two state projects. UDOT received $626,229 to implement e-Construction as a means of improving business practices [FHWA, 2017].

In order to be eligible to an AID Demonstration grant, the project must be eligible for assistance under title 23 of the United States Code. In addition, the applying agency must be prepared to initiate the project within 6 months of applying for the funding. The funding may be used for resources related to planning, financing, operation, structures, materials, pavements, environment, or construction. The project must involve an innovation that is applied to the highway transportation industry but not routinely implemented by the applicant. The application must include evidence that the innovation is more beneficial than the applicant's conventional processes. A cost estimate reflecting the requested funding should be included. Additionally, the application must include performance goals for deployment of the innovation, and these goals should reflect the following goals of the Technology Deployment Initiatives and Partnerships (TIDP):

- "Significantly accelerate the adoption of innovative technologies by the surface transportation community
- Provide leadership and incentives to demonstrate and promote state-of-the-art technologies, elevated performance standards, and new business practices in highway construction processes that result in improved safety, faster construction, reduced congestion from construction, and improved quality and user satisfaction
- Construct longer-lasting highways through the use of innovative technologies and practices that lead to faster construction of efficient and safe highways and bridges
- Improve highway efficiency, safety, mobility, reliability, service life, environmental protection, and sustainability
- Develop and deploy new tools, techniques, and practices to accelerate the adoption of innovation in all aspects of highway transportation" [Dawoud, 2016].

An FHWA evaluation team composed of technical and professional staff will review AID Demonstration applications and determine whether they are qualified based on specified selection criteria. In addition to the requirements discussed previously, the team will measure the technology readiness level (TRL) of the innovation, as defined in Table 3. The project must be at a readiness level of seven or higher.

**Table 3—Technology Readiness Levels [Dawoud, 2016]**

| Phase | TRL | Description |
|---|---|---|
| *Basic Research* | 1 | Basic principles and research |
| | 2 | Application formulated |
| | 3 | Proof of concept |
| *Applied Research* | 4 | Components validated in laboratory environment |
| | 5 | Integrated components demonstrated in laboratory environment |
| *Development* | 6 | Prototype demonstrated in relevant environment |
| | 7 | Prototype demonstrated in operational environment |
| | 8 | Technology proven in operational environment |
| *Implementation* | 9 | Technology refined and market ready |

If the application is deemed as qualified and the applicant acquires funding, it is required that award recipients submit a progress report to the FHWA within 6 months of completing the project. The purpose of this report is to document the benefits, lessons learned, and methods for implementing the innovation as standard practice [Thompson, 2016]. The applicant must be prepared to assess the effectiveness of the innovation, accept FHWA oversight of the project, conduct a customer satisfaction survey before and after implementation of the innovation, and commit to implementing the innovation as standard practice. The application process includes submitting the Standard Form 424 and a project narrative attachment [Dawoud, 2016].

### 3.3.2 | State DOT Implementation of e-Construction

Most states are employing at least some aspect of e-Construction, but they are at varying levels of implementation. The Michigan Department of Transportation (MDOT), a leader in e-Construction, has successfully applied e-Construction to design-bid-build projects since 2015. The department rates their construction administration process as 99 percent paperless. Material tickets are the only item delivered on paper [FHWA, 2016]. MDOT estimates savings of $12 million and 6,000,000 pieces of paper annually due to electronic construction administration. The department reduces its average contract modification processing time from 30 days to 3 days [FHWA, 2017]. MDOT uses software such as FieldManager for collecting field data, Mobile Inspector for daily reports, and ProjectWise for document storage. Their technology of choice is iPads after a comparison to Windows devices [FHWA, 2016].

The Florida Department of Transportation (FDOT), another leader in e-Construction, has successfully applied e-Construction to design-build projects since September of 2015 [FHWA, 2017]. FDOT uses software such as SiteManager for field project management, ProjectSolve as a collaboration platform, Electronic Document Management System (EDMS) for final archiving of project files, Hummingbird for document storage, MAC, IdenTrust for digital signatures, and Blue Beam for as-builts and field changes. FDOT believes ProjectSolve increases efficiency of communication between district administrators and consultants. FDOT added an e-Construction specification to its contract documents, which requires electronic signatures. The department's technology of choice is iPads using Citrix as the interface for accessing its other programs [FHWA, 2016].

One of the most popular software programs for document storage is ProjectWise by Bentley. This program is currently used as a tool for e-Construction by at least nine state departments of transportation: Georgia, Michigan, Missouri, Oregon, Texas, Utah, Virginia, Washington, and West Virginia [FHWA, 2016]. A case study was published by Bentley describing a highway construction project in Austin, Texas that was completed with the use of ProjectWise Integration Server, ProjectWise Passports, and ProjectWise Caching Servers. AECOM, a top transportation firm, was contracted by Central Texas Highway Constructors to provide estimates, specifications, and plans for two segments of a 27-mile, four-lane state highway. The required project timeline was 18 months, which is 50 percent faster than the average project of this size. Using Bentley ProjectWise, AECOM was able to distribute information simultaneously to a team of 120 employees from 20 different offices throughout the United States and Canada. In addition, there were six contractors working with AECOM on the project. ProjectWise allowed the team to minimize the need for travel and to maintain an updated set of design documents. The AECOM project manager noted that Bentley was available to assist the team with training and ongoing support for issues such as large data transfers, server maintenance, and user access management. ProjectWise was used for CAD file management, quality control, quality assurance, and document control with accelerated information sharing and communication. Overall, AECOM saved $600,000 in travel costs and another $250,000 in management costs. As a result, AECOM saw a return worth 12 times the original investment in ProjectWise. Additionally, the company increased its productivity by about 12 percent. This increase in productivity can be attributed to a decrease in travel time, less time spent locating and validating files, and the elimination of duplicated work by maintaining a single version of design documents [Bentley System, Inc., 2012].

AASHTOWare is another popular e-Construction platform and is currently used by several states, including Arkansas, Minnesota, Oregon, Virginia, and West Virginia [FHWA, 2016]. AASHTOWare Project in particular enables DOTs to manage information throughout both the preconstruction phase and construction phase. The software includes modules to assist with cost estimation, proposal preparation, letting bids, construction and material management and data collection. AASHTOWare Project allows users to create a consistent, integrated view of the contract process during each phase.

Additionally, it is common for state DOTs to incorporate different products provided by Adobe. For example, Iowa’s DOT utilizes Adobe Connect, which is a web conferencing software.

As previously mentioned, online meetings can save a significant amount of time and money by eliminating the need for travel. The Oregon and Washington state departments of transportation use Adobe Acrobat for accessing and annotating PDF documents. The Minnesota DOT uses Adobe Reader to create electronic contract documents for inspectors. The Missouri DOT uses the same program for document management and providing digital signatures on construction plans. Although it is not a product exclusive to the implementation of e-Construction, Microsoft Office is noted as an important program by several state DOTs. This software includes applications such as Word, Excel, PowerPoint, Outlook, OneDrive, Project, and SharePoint. Georgia, Florida, Missouri, Pennsylvania, Texas, Utah, Virginia, and Washington State use SharePoint for project collaboration and workflow as well as document storage.

Employees of state DOTs typically use a virtual private network (VPN) connection to create a secure connection from mobile devices (laptops, tablets, smartphones, etc.) in the field to their network. This private connection is especially beneficial when using public Wi-Fi. Alternatively, Citrix Receiver is used by a least five states: Florida, Minnesota, Texas, Virginia, and West Virginia. This product is free of charge and allows access to personal applications, desktops, and data from mobile devices [FHWA, 2016].

#### 3.3.2.1 | Benefits of e-Construction

An increasing number of state DOTs are becoming interested in implementing more aspects of e-Construction due to its abundant benefits. Figure 7 shows the phases of construction and examples of paperless processes created by e-Construction. In general, e-Construction provides savings in time, project cost, fuel, printing, and postage. Some of these savings then correlate to a reduced environmental impact. E-Construction also creates greater accessibility, transparency, and accountability in the workplace. Productivity is increased by having a single electronic version of construction documents and submitting and approving administrative documents electronically.

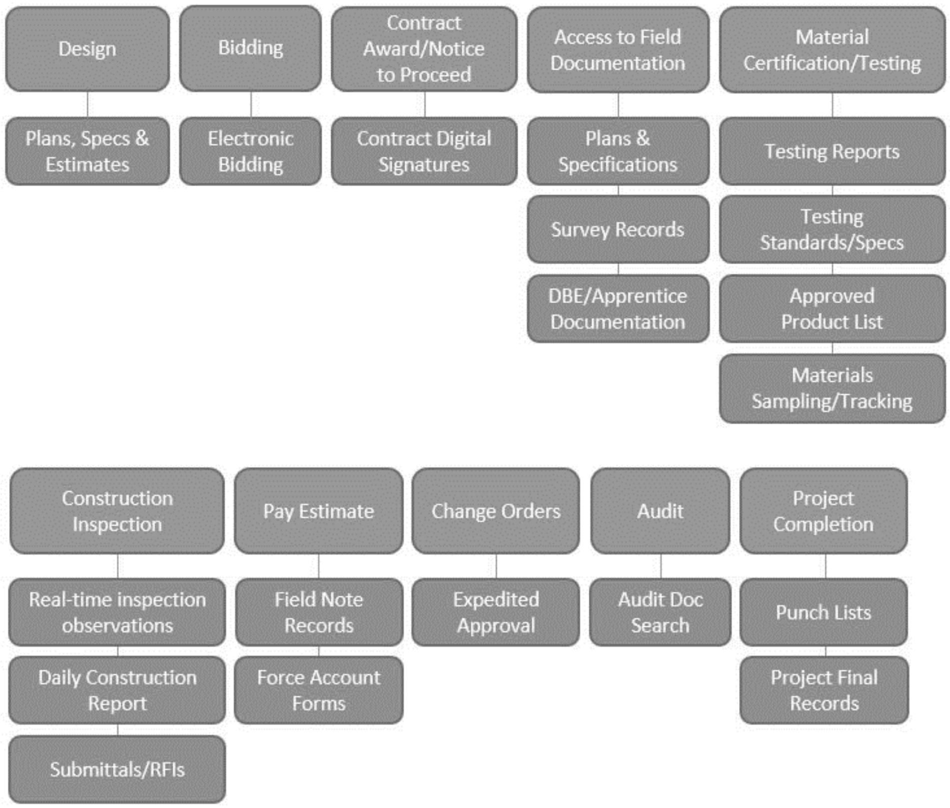


**Figure 7—Paperless Processes Created by e-Construction [Pavement Interactive, 2016]**

### 3.3.2.2 | Challenges of e-Construction

It is beneficial for state DOTs to address possible challenges associated with implementing e-Construction and to learn from successful solutions. One of the first and greatest challenges is selling the idea to state decision makers and other stakeholders. A common concern is that introducing new processes will create unnecessary stress among employees and contractors. Another concern is the up-front costs of implementing the changes. There are relatively high costs associated with e-Construction due to the required technology infrastructure, licensing software, and electronic signature management. However, it should be noted that savings in time, travel, postage, printing, and scanning accumulate if e-Construction is implemented as standard practice.

Prior to going paperless, it is beneficial to develop a memorandum of understanding between the state and construction industry leaders in order to establish common goals and to ease the transition. The Florida Department of Transportation recommends providing state leaders with an estimate of time and money savings.

Another obstacle of implementing e-Construction is a lack of resources, including hardware, software, licenses, portable devices, and personnel. With the help of information technology (IT) personnel, it is important to determine required resources and their associated costs. In order to save money throughout the research and implementation phases of this innovation, it is possible to find employees who are passionate about the transition and available to contribute additional hours of work. Neither Michigan nor Florida hired additional personnel to implement e-Construction [FDOT, 2015].

Additionally, state DOTs have discovered several information technology limitations while implementing e-Construction. First, state leaders must determine the most efficient hardware, software, and devices to provide to personnel. Despite selecting the appropriate technology, connectivity might become a problem in remote locations. FDOT states that the best solution to this issue is to have IT personnel improve the network whenever possible. Furthermore, data storage might become a concern considering any one transportation project could have hundreds of documents that will require storage in digital format. One solution is to utilize a vendor-supplied software specifically for document storage; however, this solution comes with the cost of a hosting fee. Alternatively, documents may be archived on state systems if IT personnel are able to devise a solution to create sufficient storage space. Mobile device deficiencies, including compatibility issues between devices and software, GPS data connectivity, and low battery life, could become a concern. According to FDOT, the best way to overcome this obstacle is to research available devices in relation to e-Construction needs [FDOT, 2015].

In regards to IT security concerns, IT personnel need to determine whether conventional security policies and procedures will be sufficient for the new hardware, software, and devices. In 1989, the Federal Highway Administration distributed a memorandum on the computerization of construction records. According to the administration, there are three important provisions for the collection and retention of electronic records: security of records, reliability of records, and storage of records. In terms of security, only authorized personal should have access to electronic records, and appropriate personnel should be trained to maintain its safeguard. There should be no unauthorized alteration or erasure of electronic records; however, there should be backup and recovery methods in place for accidental errors. In order to ensure the reliability of records, a procedure should be established for inputting, editing, and updating all records, including procedures for proofreading and validating data entry. The state should be able to provide evidence of program testing and computer malfunctions in order to protect its reliability. Additionally, the reliability of electronic records can be enhanced by providing an audit trail of data processing steps. Lastly, it is paramount to maintain appropriate storage and easy retrieval of electronic records throughout their life cycle [Van Ness, 1989]. Unfortunately, these information technology obstacles could possibly require additional IT personnel or vendor support to overcome training and unexpected issues.

The issue of departmental coordination requires sufficient planning to overcome. A cross-functional team representing all stakeholders should be appointed to efficiently update policies and procedures. The members of this team may include members from IT, CAD, finance, and legal groups. FDOT recommends selecting individuals from each department that are excited about the transition and being involved in the process. State leaders should establish common goals in order to prevent competing interests among stakeholders.

There will be several legal concerns associated with implementing e-Construction, particularly involving electronic and digital signatures. An electronic signature is “a version of an actual signature that is electronically embedded in a document” [FDOT, 2015]. Examples of an electronic signature include a scanned image of a written signature or a signature created using a finger or stylus on a touch-screen device. Typing initials, checking a consent box, or recording a voice or video approval are other examples of electronic signatures. The Michigan Department of Transportation utilizes this type of signature. A digital signature, however, is a more secure way to sign documents electronically. A digital signature includes signer authentication, which provides a secure connection between the signer and the signatures. Additionally, if someone changes a document after it was digitally signed, the signature would be invalidated. This process ensures data integrity. The Florida Department of Transportation utilizes digital signatures.

Regardless of which type of signature is used, it is important for state officials to determine where their state is authorized to perform such actions. If a state has signed the Uniform Electronic Transactions Act (UETA), it is approved to use electronic or digital signatures. IT personnel can determine which type of signature they feel more comfortable using based on security and data integrity. The use of digital signatures might require a licensing fee. In addition, it is important for state personnel to determine whether their state statutes and Professional Engineering Board allow the use of electronic PE stamps. State statutes, policies, and procedures must be reviewed to determine if a fully paperless e-Construction system is feasible. If current policies and procedures require hard copies of construction documents, steps will need to be taken to amend them.

Lastly, a reluctance to accept change and a lengthy learning curve should be expected among personnel. Some employees will see no deficiencies associated with the current system and not realize the benefits of e-Construction. This is why it is helpful to take the time to get the buy-in of all stakeholders associated with transportation projects. Additionally, informational material can be distributed to employees to describe the benefits of e-Construction and justify the transition. All employees will require at least some training regarding the transition to paperless construction administration. FDOT suggests testing the implementation with a small group of employees who are well suited for the e-Construction process. Their experience will provide valuable feedback to other employees and stakeholders prior to making e-Construction standard practice. All changes in policies, procedures, and processes should be well documented before the implementation process begins. If a vendor-supplied solution is implemented, the vendor might be able to provide useful documentation and training to state employees [FDOT, 2015].

## 4.0 EXPERIMENTAL PLAN

### 4.1 | Bridge Load Rating

This phase of the research was conducted by creating a finite element model of a portion of the selected bridge in ANSYS Workbench 18.2. Once the model was complete, it was validated by conducting experimental vibration testing. An accelerometer was used to test the frequency of the bridge, which was then compared to the modal frequencies of the analytical model. Finally, a load rating sensitivity analysis was conducted by varying the element conditions and loading configurations of the model.

#### 4.1.1 | Description of Bridge

The bridge that was analyzed for this study is the GDOT Bridge (ID 059-5015-0) on Sanford Drive (CR1897) in Athens, Georgia (Clarke County). The bridge spans over Tanyard Creek and a University of Georgia parking lot, as shown in Figure 8. The bridge was originally designed in 1962 by the Bridge Department of the State Highway Department of Georgia using the AASHO 1961 Design Guide. It was designed to support typical H20-S16 and/or military loading. The future paving allowance was designed to be 15 psf (0.718 kPa). Currently, the Sanford Drive Bridge is usually only open to buses, including University of Georgia (UGA) Campus Transit buses, Athens Transit buses, and smaller community shuttles. The bridge is load-posted with the weight limits shown in Figure 9. The weight limit for two and three-axle single unit trucks is 15 tons. The weight limits for three-axle single trailer trucks, four-axle multi-trailer trucks, and five-axle single trailer trucks are 16 tons, 18 tons, and 20 tons, respectively.

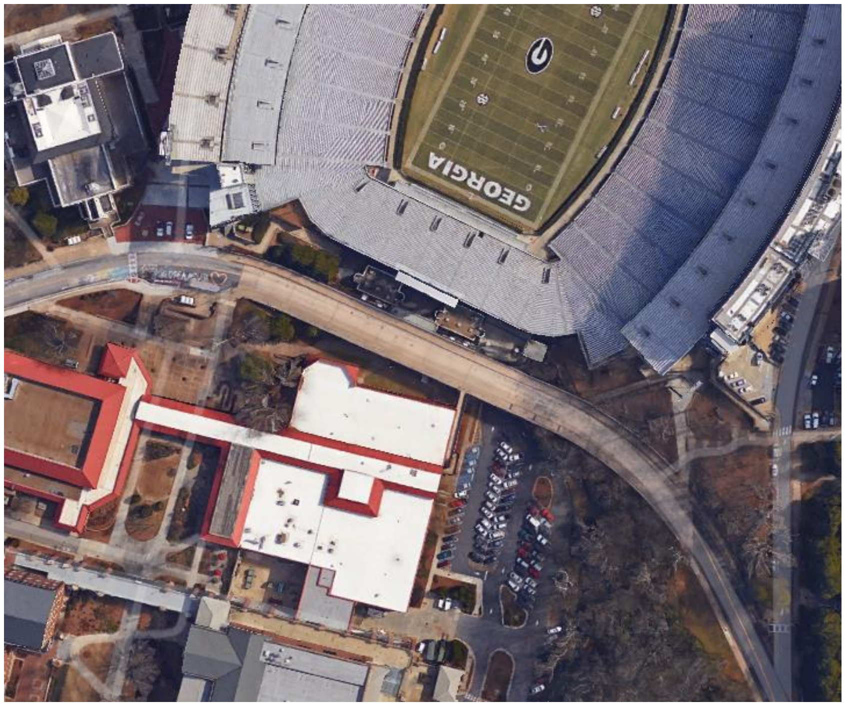


**Figure 8—Aerial View of Bridge [Google Maps]**

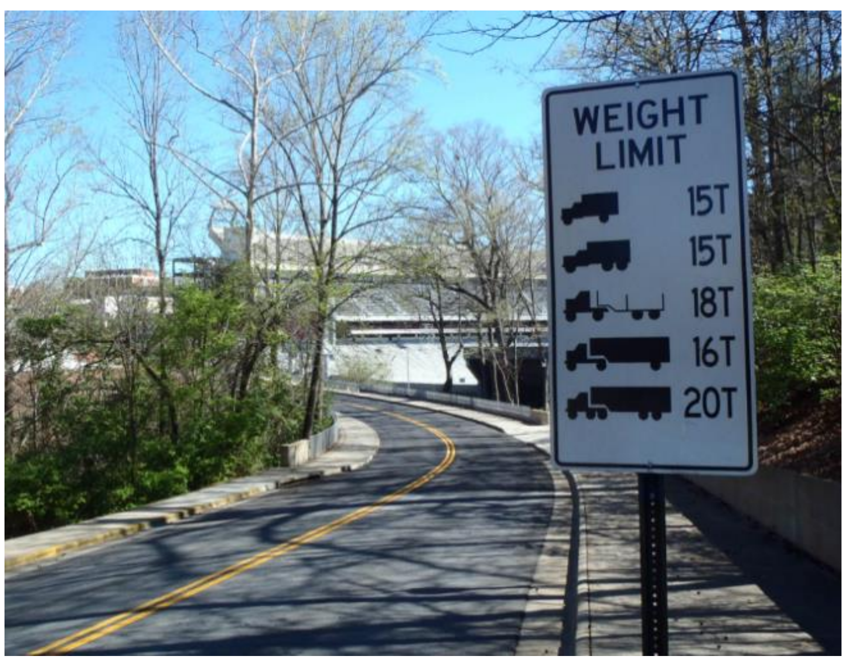


**Figure 9—Bridge Weight Limits [GDOT, 2017]**

#### 4.1.1.1 | Overview

The bridge superstructure is composed of ten simply supported spans. As Figure 10 shows, the spans range in length from 40 ft 7 in (12.37 m) to 66 ft (20.12 m), and the overall length of the bridge is 554 ft (168.86 m). The bridge consists of two 17 ft (5.18 m) lanes serving traffic in both directions.

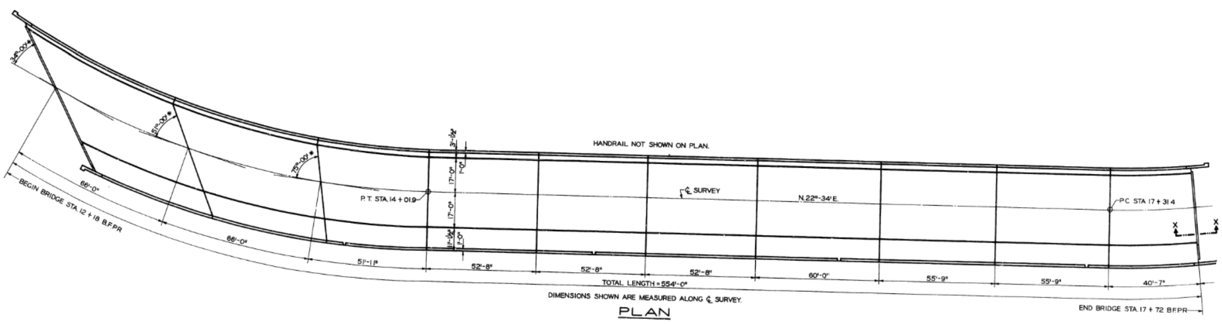


**Figure 10—Plan View of Bridge**

There are seven WF 36 x 150 steel I-beams across each span spaced at 6 ft 8 in (2.03 m) center-to-center. The bridge elevation is shown in Figure 11 and Figure 12. The beams were originally painted with lead paint but subsequently repainted with a lead chromate oil alkyd paint system in 1990. The bridge superstructure consists of concrete diaphragms at 90 degrees to the longitudinal beams. The concrete substructure is composed of one concrete end bent, nine concrete intermediate bents, and one steel H-pile bent. An elevation view of the bridge and a typical bent detail for the center spans are shown in Figure 13 and Figure 14. The total cross-sectional width of a typical bent is 43 ft 2 in (13.16 m), and the overhang dimension is 6 ft 9 in (2.06 m). The bent columns are 3 ft x 3 ft (0.91 m x 0.91 m). There are lights attached to the concrete caps, and several 1-inch (25.4 mm) electrical conduits are attached to the caps, beams, and bottom of the overhang. The bridge has a 6.625 in (168.28 mm) concrete deck with a 2 in (50.8 mm) asphalt overlay that was added in 2016.

**Figure 11—Bridge Elevation [GDOT, 2017]**

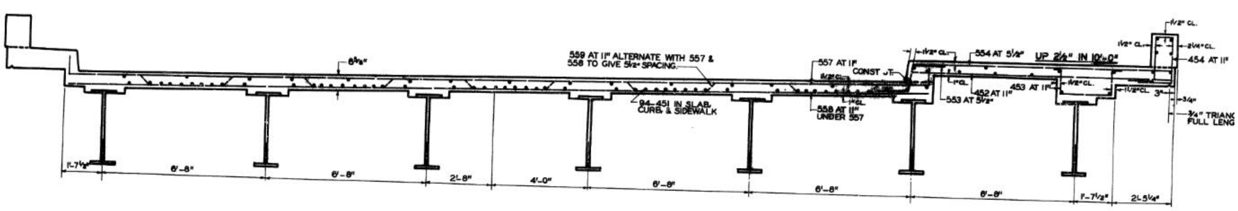


**Figure 12—Bridge Cross-Section Elevation Drawing**

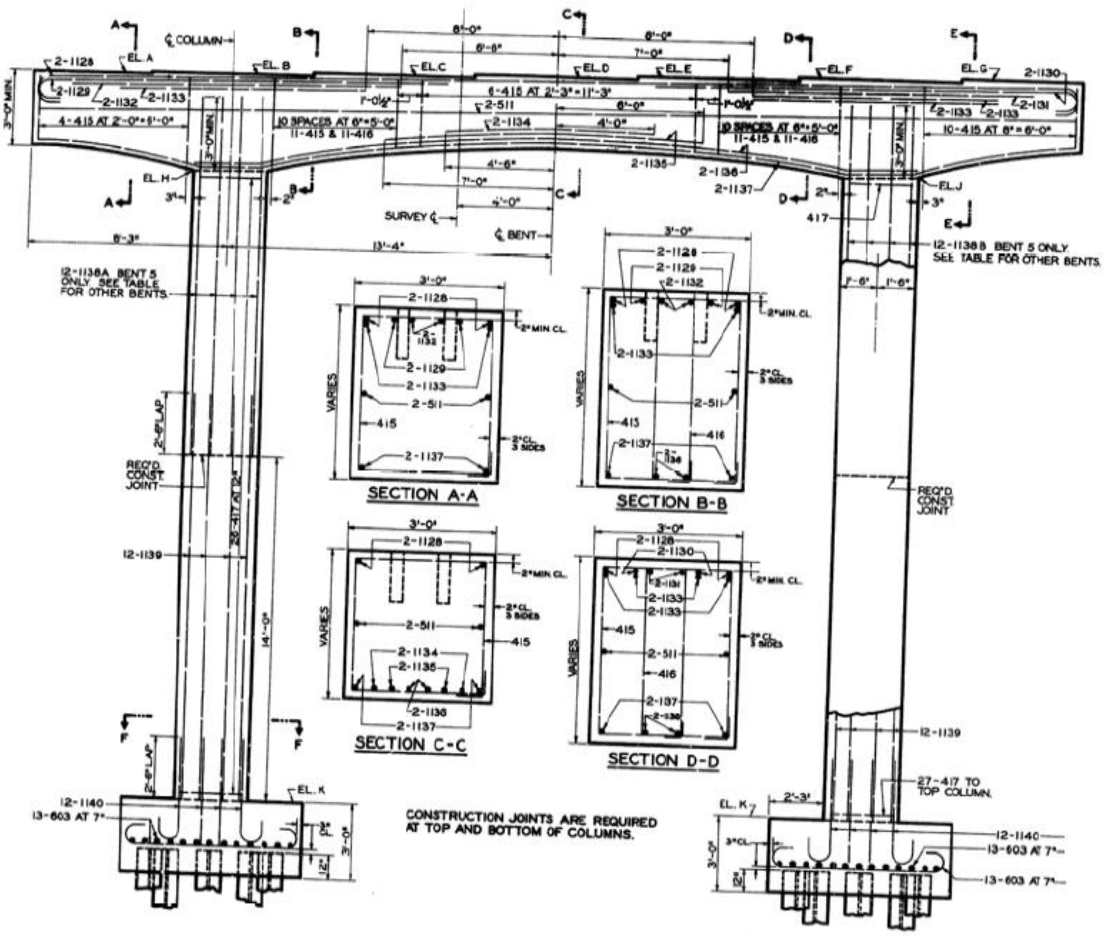


**Figure 13—Bent Elevation View Detail**

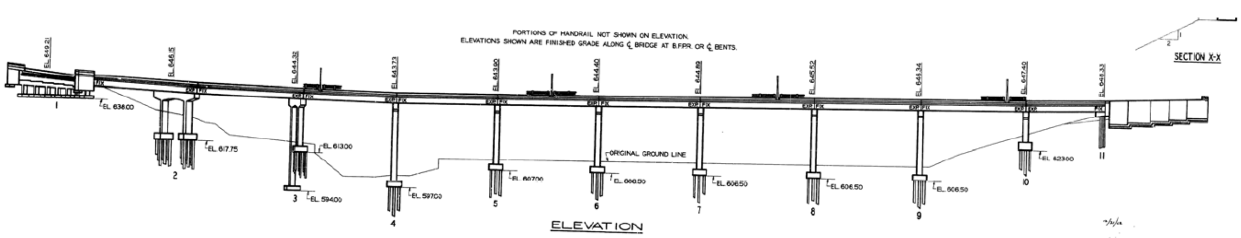


**Figure 14—Bridge Elevation**

### 4.1.1.2 | Existing Bridge Condition

The Sanford Drive Bridge was inspected on March 8, 2017 by GDOT. The National Bridge Inspections Standards (NBIS) condition of the deck was determined to be a 6 (satisfactory condition). The inspectors discovered spalling, cracking, and light efflorescence in the deck. The bridge superstructure has a NBIS condition rating of 4 (poor condition). Both end walls have hairline cracking, and all steel beams and bearings have paint failure with minor corrosion. There is significant section loss and corrosion at the beam ends. Figure 15 shows beam deterioration and a section loss of 0.25 in (6.35 mm) in the bottom flange of a beam. The inspection findings for the superstructure are summarized in Table 4. The abbreviations in the table represent forward (F) and rear (R).

**Figure 15—Superstructure Deterioration: (a) Deterioration in Web and Bottom Flange (b) Section Loss of 0.25 in [GDOT, 2017]**

**Table 4—Superstructure Inspection Data**

| Bent | Component | Condition |
|---|---|---|
| *Bent 2* | Bearing 7 | Minor corrosion with section loss |
| | Beam 6 (F) | Heavy section loss in beam ends, bottom flange, top flange, and bearing |
| | Beam 7 (F) | Heavy section loss in beam ends, bottom flange, top flange, and bearing |
| *Bent 3* | Beam 6 (R) | Minor section loss in web |
| | Beam 7 (F,R) | Minor section loss in beam end, bottom flange, top flange |
| *Bent 4* | Beam 7 (F,R) | 1/4" section loss in both flanges and both web faces |
| *Bent 5* | Beam 6 | Minor section loss in beam ends |
| | Beam 7 | 1/4" section loss in beam end (F), bottom flanges (F,R), and both web faces |
| *Bent 6* | N/A | Pack rust on bearing, minor corrosion and paint loss |
| | Beam 7 (F) | 1/4" section loss in web |
| | Beam 7 (R) | 1/4" section loss in both web faces |
| *Bent 7* | N/A | Minor pack rusting on bearings |
| | Beam 5 | Minor section loss in bearing and web at beam end |
| | Beam 7 | Minor section loss in bearing and right top flange |
| | Beam 7 (F) | 1/4" section loss in both web faces |
| *Bent 8* | Beam 7 (F,R) | Minor section loss at beam ends |
| *Bent 9* | Beam 5 (F,R) | Minor section loss in web |
| | Beam 6 (F,R) | Minor section loss in web |
| | Beam 7 (F,R) | Minor section loss at beam ends |
| *Bent 10* | Bearings | Minor section loss, corrosion, and pack rust |
| | Beam 4 (F) | 1/4" section loss in bottom flange and beam end |
| | Beam 5 (F) | 1/4" section loss in bottom flange and beam end |
| | Beam 6 (F) | 1/4" section loss in bottom flange and beam end |

The bridge substructure has a NBIS condition rating of 6 (satisfactory condition). The substructure is experiencing minor cracking in several locations, as shown in Figure 16. The substructure inspection findings are summarized in the Table 5.

**Figure 16—Horizontal Crack in Bent Cap [GDOT, 2017]**

**Table 5—Substructure Inspection Data**

| Component | Location | Condition |
|---|---|---|
| *Abutments* | Abutment Caps | Minor vertical cracking |
| | Abutment 1 Back Wall | Minor cracking |
| | Abutment 1 Cap | Horizontal crack/delamination in bay 4 |
| *Bent Caps* | N/A | Exposed high chairs on bottom |
| | Bent 2 | Minor cracking on the bottom |
| | Bent 3 | Longitudinal cracking & delamination in forward face at light mount under beam 4 |
| | Bent 5 | Minor cracking, hairline crack in left column |
| | Bent 10 | Minor dirt present |
| | Bents 2-10 | Hairline vertical cracking at the step-down |
| | Bents 2-3, 6-8 | Pop outs with exposed rebar |
| *Columns* | N/A | Minor surface cracking |
| | Bent 4 | Small pop out to rebar in forward side of left column |
| *Banks* | Bent 10 | Erosion |

### 4.1.2 | Description of FEA Model

The finite element model of the bridge was created in ANSYS Workbench 18.2. The following section details the model geometry, material properties, meshing, and boundary conditions. The verification and validation of the model, unit loading plan, and sensitivity analysis are discussed in this section as well.

#### 4.1.2.1 | Model Geometry

In order to simplify the geometry of the model and prevent redundancy, three spans were selected to be modeled. Spans 6, 7 and 8 were selected from the center of the bridge. The lengths of Span 6, Span 7, and Span 8 are 52 ft 8 in (16.05 m), 60 ft (18.29 m), and 55 ft 9 in (16.99 m), respectively. The spans that were modeled are shown in Figure 17. These spans were selected to model various span lengths, including the longest straight span, which was expected to be the critical case for load rating. The bridge deck was consistently modeled as 6.625 in (168.28 mm) thick. Although bridge superstructure is the focus of this research, a generalized version of Bents 6,7, 8, and 9 were modeled to create the appropriate boundary conditions of the bridge with steel plates and bearing plates. The spacing between the WF sections where they meet in between spans was assumed to be 4 in (101.6 mm) based on inspection photos. The drawings specified the anchor bolts to be 1 in (25.4 mm) in diameter and 1 ft 6 in (0.46 m) long with 3 in x 3 in (76.2 mm x 76.2 mm) cut washers and hex nuts. Figure 18 and 19 show an isometric view and elevation view of the bridge model.

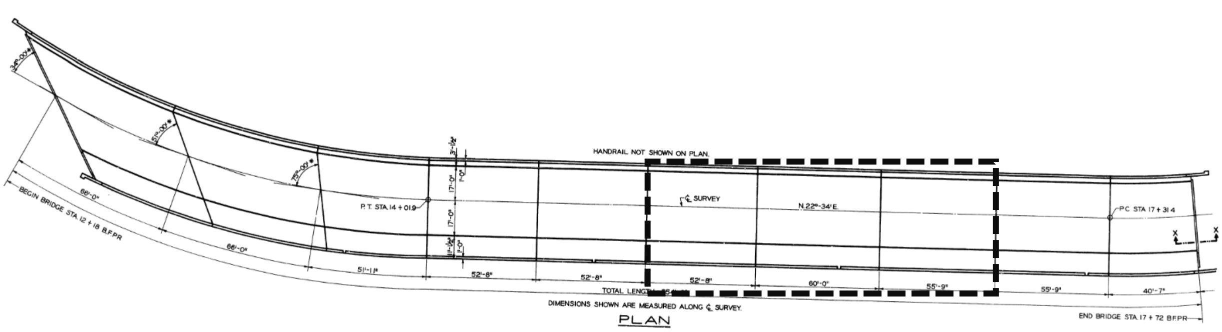


**Figure 17—Spans Selected for FEA Model**

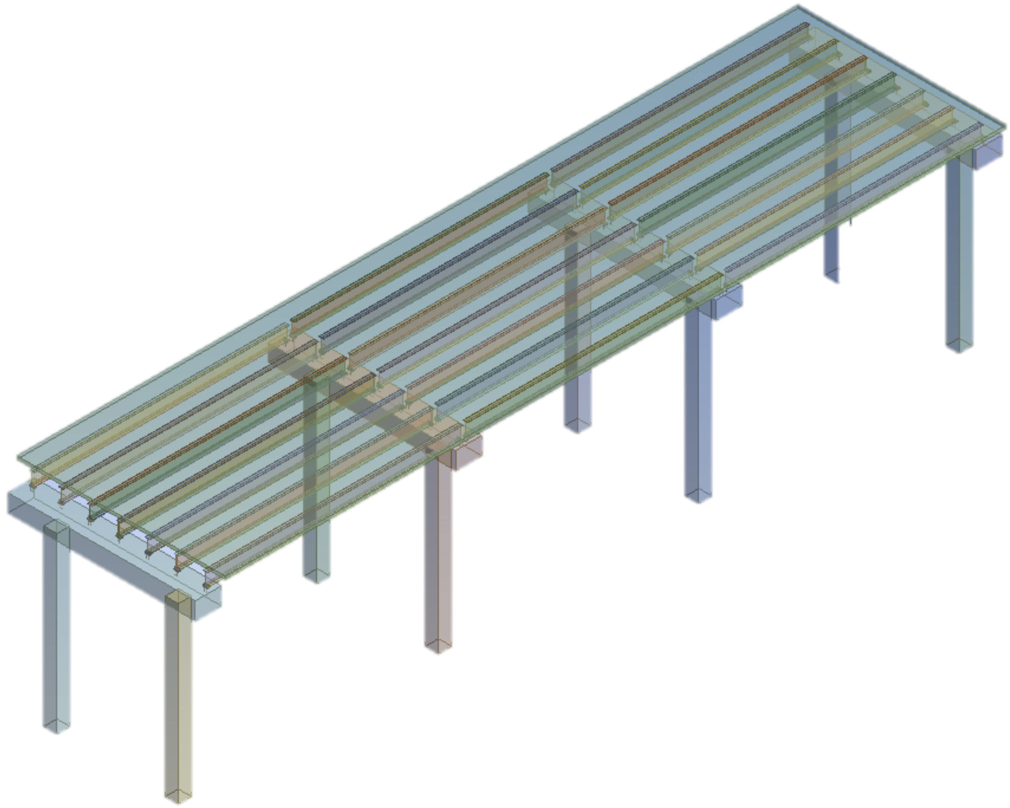

**Figure 18—Isometric View of Bridge Model**

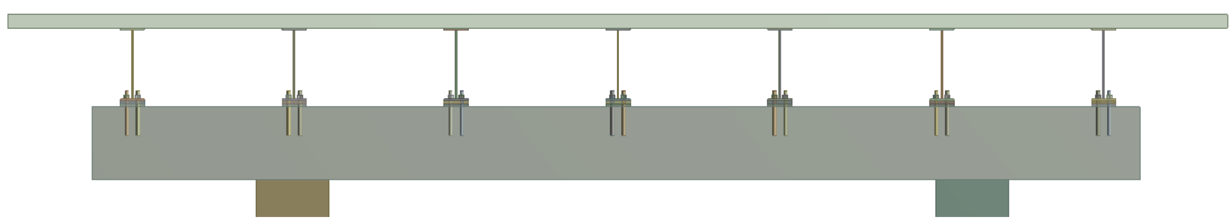

**Figure 19—Elevation View of Bridge Model**

#### 4.1.2.2 | Material Properties

The deck, diaphragm, and bents of the bridge are concrete. The drawings for the bridge indicate that these components were constructed with Class A (general purpose) concrete per Georgia Standard. According to Georgia Department of Transportation Bridge Specifications, Class A concrete has a minimum 28-day compressive strength of 3,000 psi (20.68 MPa) with a standard deviation of 650 psi (4.48 MPa) [GDOT, 2006]. The drawings specify that all beams and cover plates are A-36 steel, and all other structural steel is either A-36 or A-7 steel. Since the existing material properties are unknown and this study is a proof of concept, the concrete elements were defined as the default linear concrete in ANSYS. The steel I-beams, bearing plates, and anchor bolts were defined as default structural steel. The ANSYS default material properties of both the concrete and the structural steel are shown in Table 6.

**Table 6—Material Properties**

| Property | Concrete | Structural Steel |
|---|---|---|
| Density | 143 lb/ft$^3$ | 1.728 lb/ft$^3$ |
| Modulus of Elasticity | 4,351 ksi | 29,008 ksi |
| Poisson's Ratio | 0.18 | 0.30 |
| Tensile Yield Strength | 0 psi | 36,259 psi |
| Compressive Yield Strength | 0 psi | 36,259 psi |
| Tensile Ultimate Strength | 725 psi | 66,717 psi |
| Compressive Ultimate Strength | 5,947 psi | 0 psi |

#### 4.1.2.3 | Meshing

The mesh of the model was created using the hex dominant method. A hex dominant mesh is useful for bodies with large amounts of interior volume. Using this method, ANSYS ensures the ratio between each element's normalized volume and surface area is greater than or equal to 2. In addition to the hex dominant method, body sizing was added to create more uniform face meshing of the beams. CONTA174 and TARGET170 elements were used to create the bonded contact between the bearing plates and the beams. CONTA174 is an 8-node element used to represent contact and sliding between its deformable surface and 3-D target surfaces, which are the TARGE170 elements. Each node of a CONTA174 element has three degrees of freedom. The TAGE170 elements are discretized by a set of target segment elements and paired with an associated contact surface. Translational displacement, rotational displacement, forces, and moments can be imposed on target elements. SOLID186 elements were used for the rest of the structure, including the bridge deck, beams, and bearing plates. This type of element is a higher order 20-node solid element with three degrees of freedom per node. It exhibits quadratic displacement behavior and is usually used for elastic materials. Figure 20 shows the mesh of the sidewalk, deck, beams, bearing pads, and steel plates.

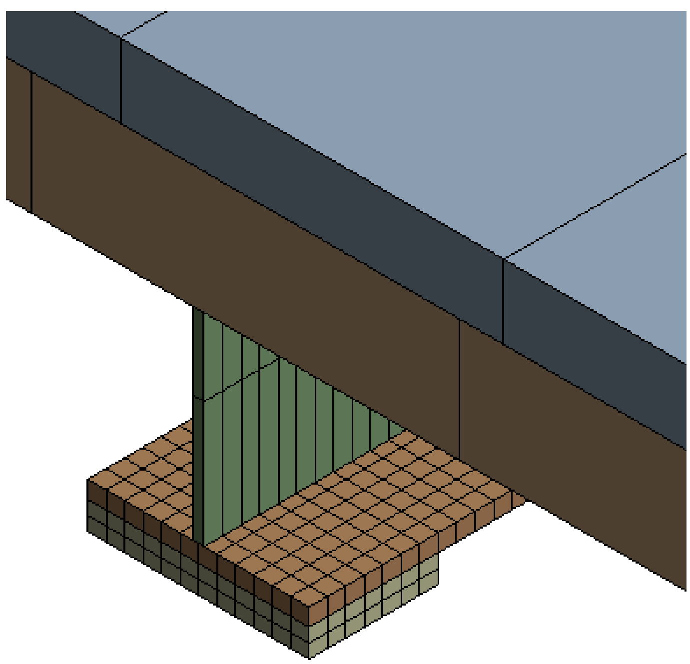

**Figure 20—Model Mesh**

#### 4.1.2.4 | Boundary Conditions

The drawings show that the bridge is simply supported with alternating fixed and expansion joints. The ANSYS model was supported with displacement supports, one on the face of each bearing plate. The supports were free to move only in the x and z-directions. However, the bearing plates were given bonded contact with the beams to prevent reactions in the x-direction. A perfect bond was assigned between the base of the beams and the plates to ensure a conservative approach. The anchor bolts and the substructure were suppressed for this analysis.

#### 4.1.2.5 | Verification & Validation Plan

The finite element model was verified by observing equilibrium after generating arbitrary loading conditions and analyzing subsequent reactions. Additionally, the self-weight of the structure was determined to verify its density. Then, a modal analysis was conducted in ANSYS to determine the fundamental frequency of the structure independent of any loading. In order to validate these results, vibration testing was conducted on the bridge. A PCB Piezotronics accelerometer (Model #352C34) was placed on the sidewalk of Span 7 to determine the frequency of vibration due load patterns that were expected to induce the fundamental frequency of the bridge. The response data that was recorded in the time domain was converted to the frequency domain using fast Fourrier transforms. The component frequencies, spread across the frequency spectrum, were represented as peaks in the frequency domain. If the experimental peak frequency was within the analytical natural frequency ± 1 Hz, the model was considered to be validated with the correct mass and stiffness.

Although strain gauges are typically used for experimental load testing, they were not used for this study due to limited access to the beams underneath the bridge. Additionally, the paint on the steel beams would need to be removed for proper contact between the bridge and the strain gauges, which was not plausible for this study. Transient loading was not used to validate the bridge since only one accelerometer was available for this study.

#### 4.1.2.6 | FEA Load Testing Plan

Once the bridge model was verified and validated, unit loads were individually applied to nodes on the bridge deck. The mesh of the bridge deck created 23.2 in (589.3 mm) x 24 in (609.6 mm) rectangles. The loading was applied as 1 lbf (4.45 N), but the results were post-processed based on the gross vehicle weight rating (GVWR) of a UGA Campus Transit bus, as shown in Table 7. This loading was selected over Athens Transit loading because UGA Campus Transit busses run more often and are usually more heavily occupied. The weight rating of the vehicle is 42.5 kips (19.3 tons), and the distance between the front axle and rear axle is 23.6 ft (7.19 m). The wheel contact area was assumed to be 10 in x 20 in (101.60 mm x 203.20 mm).

**Table 7—UGA Campus Transit Bus Information**

| Measurement | Dimension |
|---|---|
| Length (over bumpers) | 41.0 ft |
| Width | 8.50 ft |
| Height | 10.5 ft |
| Wheelbase | 23.6 ft |
| Width of Front Tire | 8.0 in |
| Width of Rear Tire | 9.75 in |
| Turning Radius | 44.0 ft |
| Approach/Departure Angle | 9° |
| Approx. Vehicle Weight | 28,125 lbs |
| Gross Vehicle Weight Rating (GVWR) | 42,540 lbs |

#### 4.1.2.7 | Sensitivity Analysis

Lastly, a sensitivity analysis was conducted to determine how the condition of bridge superstructure elements affects the overall load rating of the structure. The Sanford Drive Bridge has corrosion and section loss in many of its beams; however, since this study is a proof of concept, only one beam was selected for the analysis. The center span was the focus of this study since it is the longest span. Assuming the buses travel in the center of each lane, the wheel contact area is as shown in Figure 21. Since one of the bus wheels travels almost directly over the center girder (SP7-WF4), it was selected as the bridge element for probing the worst-case results. Deterioration effects were tested in the bottom flange, top flange, web, and a combination of these locations during the post-processing of results.

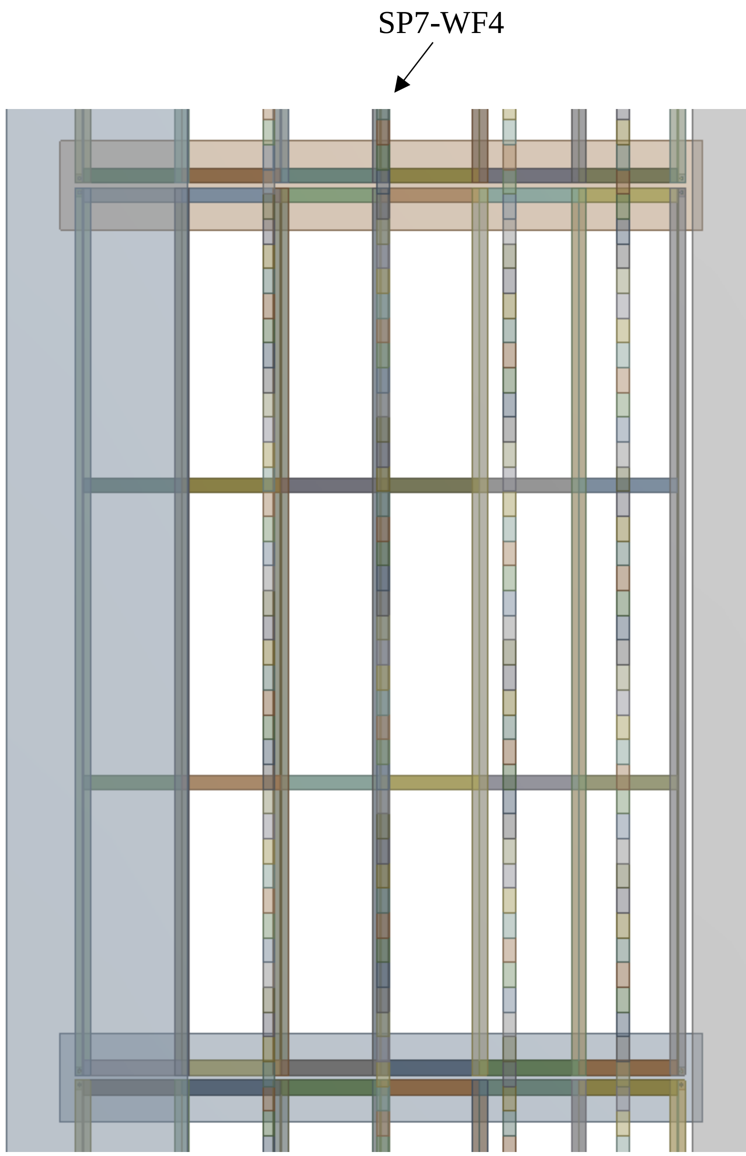


**Figure 21—Span 7, Girder 4**

### 4.2 | E-Construction

This phase of the research was conducted by identifying the required departmental offices and documentation that need to be incorporated into GDOT's e-Construction program. In order to document current construction management software systems and field data collection within the context of GDOT's workflow processes as described by the Plan Development Process (PDP), meetings were conducted with various GDOT offices. The meeting schedule is shown in Table 8. Technical and organizational barriers within the current processes were identified by each office.

Additionally, a thorough review of other state DOT e-Construction practices was conducted to identify their paperless status, software used, field data collection technologies, and workflow processes. Both challenges and benefits seen by other transportation agencies were recorded. Following this research, a proposal for the FHWA AID Demonstration was drafted. The project team reached out to other state DOTs that have previously received funding for e-Construction through the AID Demonstration program, including the Kansas Department of Transportation and the Ohio Department of Transportation. Using all of this information as reference material, the required Project Narrative was completed, which includes the following: Project Abstract, Project Description, Innovation Performance, Application Information and Coordination, Funding Request, Eligibility and Selection Criteria, and Additional Attachments. The draft will be reviewed by GODT and revised for submission.

**Table 8—GDOT Office Meeting Plan**

| | Meeting Date | Office | Division |
|---|---|---|---|
| **1** | November 13, 2017 | Construction | Construction |
| **2** | March 16, 2018 | Materials and Testing | Construction |
| **3** | April 18, 2018 | Roadway Design | Engineering |
| **4** | April 18, 2018 | Program Control | Program Delivery |
| **5** | April 20, 2018 | Construction Bidding Administration | Construction |
| **6** | April 24, 2018 | Bridge Design & Maintenance | Engineering |
| **7** | April 26, 2018 | Design Policy & Support | Engineering |
| **8** | April 26, 2018 | IT Application Support | Information Technology |
| **9** | April 30, 2018 | Environmental Services | Engineering |
| **10** | May 7, 2018 | Planning | Planning |
| **11** | May 8, 2018 | Engineering Services | Engineering |
| **12** | May 9, 2018 | Right-of-Way | Engineering |
| **13** | May 9, 2018 | IT Infrastructure | Information Technology |
| **14** | May 14, 2018 | Program Delivery | Program Delivery |
| **15** | May 23, 2018 | Innovative Delivery | P3 |

## 5.0 EXPERIMENTAL RESULTS

### 5.1 | Bridge Load Rating

The following section includes the results from the experimental vibration testing used to validate the bridge model as well as load-rating results from the influence surface area method and sensitivity analysis.

#### 5.1.1 | Validation

After running a Modal Analysis in ANSYS, it was determined that Mode 4 shows the deflected shape and frequency that is most likely to occur from traffic loading. According to a University of Georgia Campus Transit representative, the size of the bus tires is 305/70R-22.5. The overall diameter of the tire is 39 in (990.6 mm). Assuming the buses travel at the speed limit, 25 mph (11.176 m/s), the frequency of rotation of one tire is calculated to be 3.59 revolutions per second (RPS). Since the rotations of the front axle and rear axle are not synchronized, the number can be doubled to determine the total effect of the bus. Therefore, the frequency of rotation of the bus is 7.18 RPS, which is similar to the 8.76 Hz frequency from the modal analysis. The total deformation of Mode 4 is shown in Figure 22.

Furthermore, it was determined that the frequency of Mode 11 could be due to the vibration of the bus engine. Depending on the engine model, the frequency ranges anywhere from 1,000 to 2,000 revolutions per minute (RPM). If the vehicle is idling, it will be 1,000 RPM, which is equal to 16.67 RPS, which is similar to the 13.926 Hz frequency from the modal analysis. Figure 23 shows the deflected shape of Mode 11.

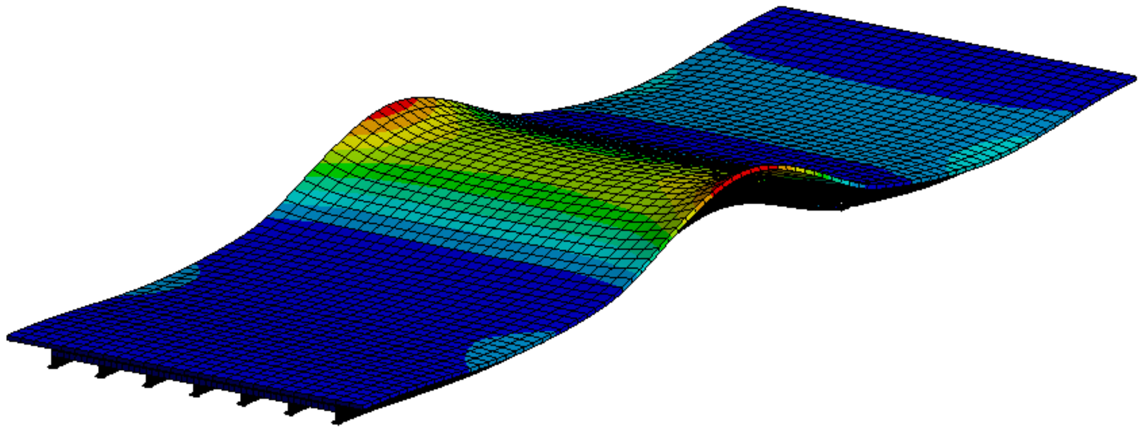

**Figure 22—Mode 4 Total Deformation**

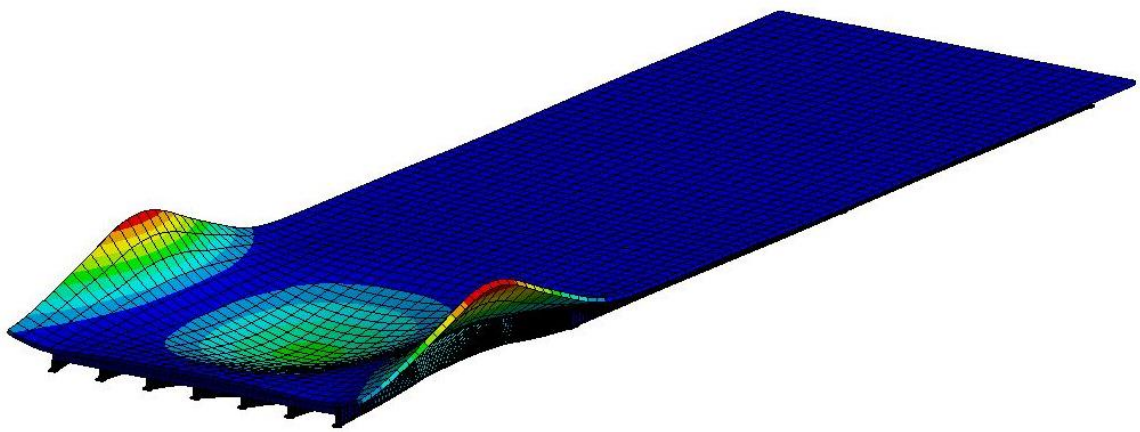

**Figure 23—Mode 11 Total Deformation**

Vibration testing was conducted on the bridge on April 17, 2018 and May 1, 2018. The testing setup is shown in Figure 24. Construction glue was used to adhere the accelerometer to the sidewalk on the North side of the bridge to ensure consistent readings. The accelerometer was set to record at a rate of 500 points per second. For each reading, the lane and bus type (UGA Campus Transit or Athens Transit) was recorded.

**Figure 24—Accelerometer Setup**

As expected, most of the readings peaked near 8 Hz and 15 Hz, which coincides with the frequencies of Mode 4 and Mode 11. As shown in Table 9, the average frequency for an approximation of Mode 4 was 7.852 Hz. The average frequency for an approximation of Mode 11 was 14.988 Hz. The data that belongs in the blank spaces were outliers and were removed from the data set. Table 10 shows a summary of the expected calculated frequencies, the experimental frequencies, and the frequencies from the ANSYS modal analysis. Since the experimental peak frequencies are approximately within the analytical natural frequencies ± 1 Hz, the model was considered to be validated with the correct mass and stiffness.

**Table 9—Vibration Testing Results**

| Reading | Lane | Bus Type | Approx. Mode 4 Frequency (Hz) | Approx. Mode 11 Frequency (Hz) |
|---|---|---|---|---|
| **1** | North | UGA | 7.935 | - |
| **2** | North | UGA | 8.057 | 14.771 |
| **3** | South | UGA | - | - |
| **4** | North | UGA | 7.935 | 14.771 |
| **5** | North | UGA | 7.935 | - |
| **6** | South | Athens | 8.057 | 14.771 |
| **7** | North | UGA | - | 15.625 |
| **8** | North | UGA | 7.813 | 14.648 |
| **9** | North | UGA | 7.935 | 14.893 |
| **10** | North | Athens | 7.935 | 14.771 |
| **11** | North | UGA | - | 15.625 |
| **12** | North | UGA | 7.813 | 14.648 |
| **13** | South | Athens | 7.183 | 14.648 |
| **14** | North | Athens | 7.813 | 14.648 |
| **15** | North | UGA | 7.813 | 14.771 |
| **16** | North | UGA | - | 15.625 |
| **17** | North | UGA | 7.813 | 14.648 |
| **18** | North | UGA | 7.935 | 14.771 |
| **19** | North | UGA | 7.813 | 14.648 |
| **20** | North | UGA | - | 15.625 |
| **20** | North | Athens | - | 15.869 |
| | | **Average** | 7.852 | 14.988 |

**Table 10—Frequency Summary**

| | Expected Freq. (Hz) | ANSYS Modal Freq. (Hz) | Experimental Freq. (Hz) | Modal vs. Experimental Percent Difference |
|---|---|---|---|---|
| **Mode 4** | 7.180 | 8.428 | 7.852 | 7.076 % |
| **Mode 11** | 16.670 | 13.926 | 14.988 | 7.346 % |

### 5.1.2 | Load Testing

Prior to applying unit loads to the model, the worst loading case was determined by hand calculations. Figure 25 shows the vehicle configuration that was used to apply the loads. The first set of axles are 18 ft (5.49 m) from the left side of the 60 ft (18.3 m) span. The second set of axles are 18.4 ft (5.61 m) from the first, and the third set of axles are 23.6 ft (7.19 m) further along the span.

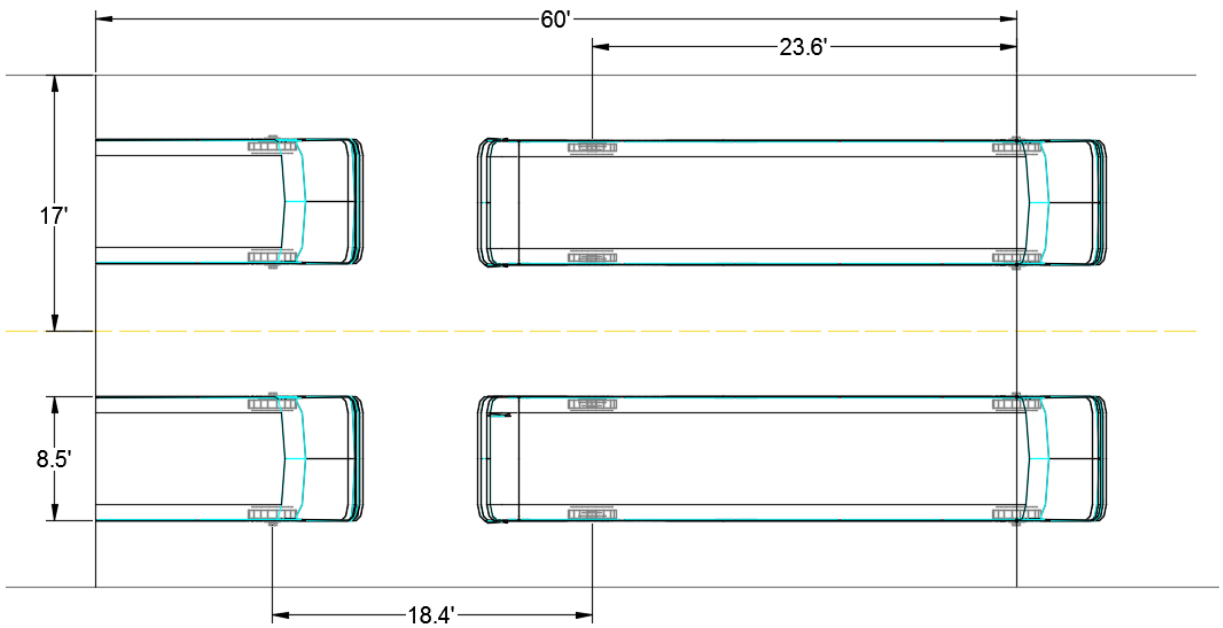


**Figure 25—Vehicle Loading Configuration**

In order to demonstrate how this method could be used to determine rating factors based on the vehicle position shown in Figure 25, unit loads were applied to nearby node locations. A unit load of 1 lbf (4.45 N) was individually applied to each of the nodes shown in Figure 26. A separate ANSYS module was ran for each nodal force, and results were collected each time. A self-weight case with the force of gravity was conducted as well. The Equivalent (von-Mises) Stress (psi) was recorded from seven locations in the flange of beam SP7-WF4, as shown in Table 11. The Maximum Shear Stress (psi) was recorded from seven locations in the web of the same

WF section, as shown in Table 12. Locations were selected near the supports as well as at the quarter and center points of the beam.

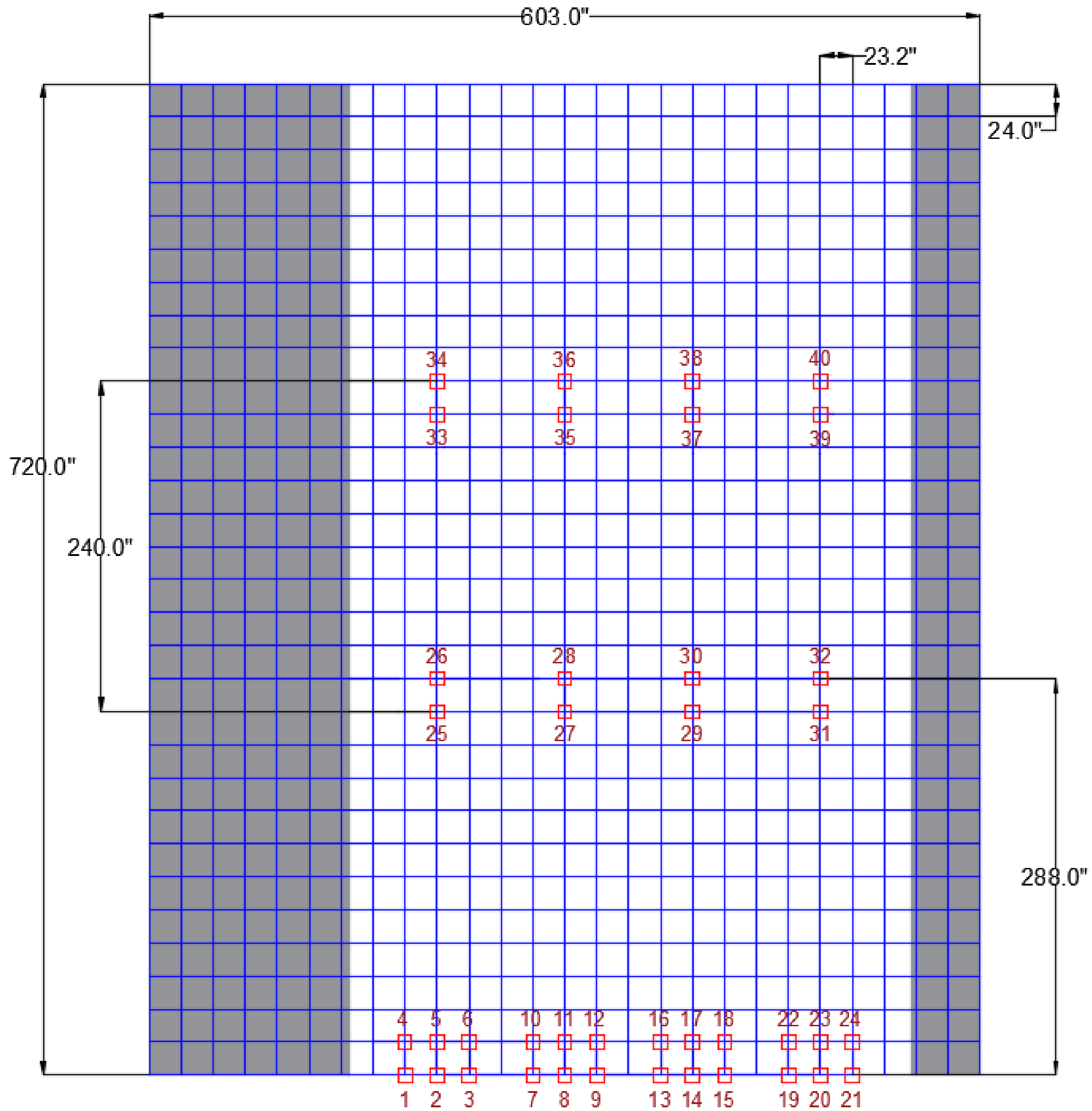


**Figure 26—Unit Load Layout**

**Table 11—Result Locations for Equivalent Stress**

| Location | Description | X | Y | Z | Node ID |
|---|---|---|---|---|---|
| **1** | Near left support | 230 | 274 | 1377 | 3254173 |
| **2** | Away from left support | 230 | 274 | 1367 | 3254183 |
| **3** | Quarter Point | 230 | 274 | 1171 | 3254379 |
| **4** | Center | 230 | 274 | 1029 | 3254521 |
| **5** | Quarter Point | 230 | 274 | 950 | 3254600 |
| **6** | Away from right support | 230 | 274 | 691 | 3254859 |
| **7** | Near right support | 230 | 274 | 681 | 3254869 |

**Table 12—Result Locations for Maximum Shear**

| Location | Description | X | Y | Z | Node ID |
|---|---|---|---|---|---|
| **1** | Near left support | 224.32 | 281.75 | 1380 | 4410614 |
| **2** | Away from left support | 224.32 | 288.55 | 1370 | 4411339 |
| **3** | Quarter point | 224.32 | 288.55 | 1208 | 4411501 |
| **4** | Center | 224.32 | 288.55 | 1029 | 4411680 |
| **5** | Quarter point | 224.32 | 288.55 | 850 | 4411859 |
| **6** | Away from right support | 224.32 | 288.55 | 688 | 4412021 |
| **7** | Near right support | 224.32 | 281.75 | 678 | 4411316 |

After the data was collected, each result for Equivalent Stress and Maximum Shear was multiplied by the load of the corresponding bus wheel. Since the engine is located in the back of the bus, an unequal distribution was used for the loading. For a 40 ft (12.2 m) commercial bus, 65% of its load is distributed to the rear axle, and 35% of its load is distributed to the front axle (MORR Transportation Consulting, 2014). Since the total GVWR of the UGA Campus Transit bus is 42.54 kips (19.3 tons), this translates to 7.445 kips (3.723 tons) for each front wheel and 13.83 kips (6.915 tons) for each rear wheel. The moment demand and shear demand were then calculated for the self-weight case and each node case using Eq. 3 and Eq. 4. Composite deck action was not considered for this study.

$$M_{demand} = \frac{\sigma_{equiv.} \times I}{c} \qquad \textbf{Eq. 3}$$

Where: $I = \frac{1}{12}bh^3$

$$c = \frac{d}{2}$$

$$V_{demand} = \frac{2}{3}(V_{max} \times A_{web})$$ **Eq. 4**

Once the demand for each node was calculated, two vehicle positions were considered based on the worst-case loading configuration. According to a University of Georgia Campus Transit representative, the width of the front bus tire is 8.0 in (203.2 mm), and the width of the rear bus tire is 9.75 in (247.65 mm). Therefore, a conservative approach was taken by considering the standard AASHTO wheel contact area of 20 in (508 mm) x 10 in (254 mm). Position 1 includes the self-weight case and the corresponding nodes, assuming each wheel load was centered over a single node. The nearest nodes were selected, as shown in Figure 27. Position 2 includes the self-weight case and the corresponding nodes assuming each wheel load was unevenly spaced between two nodes. The nodes used for this position are shown in Figure 28, indicating 60% of each wheel load being distributed to the bottom node, and 40% of each wheel load being distributed to the top node. For each position, the total moment demand and total shear demand was determined.

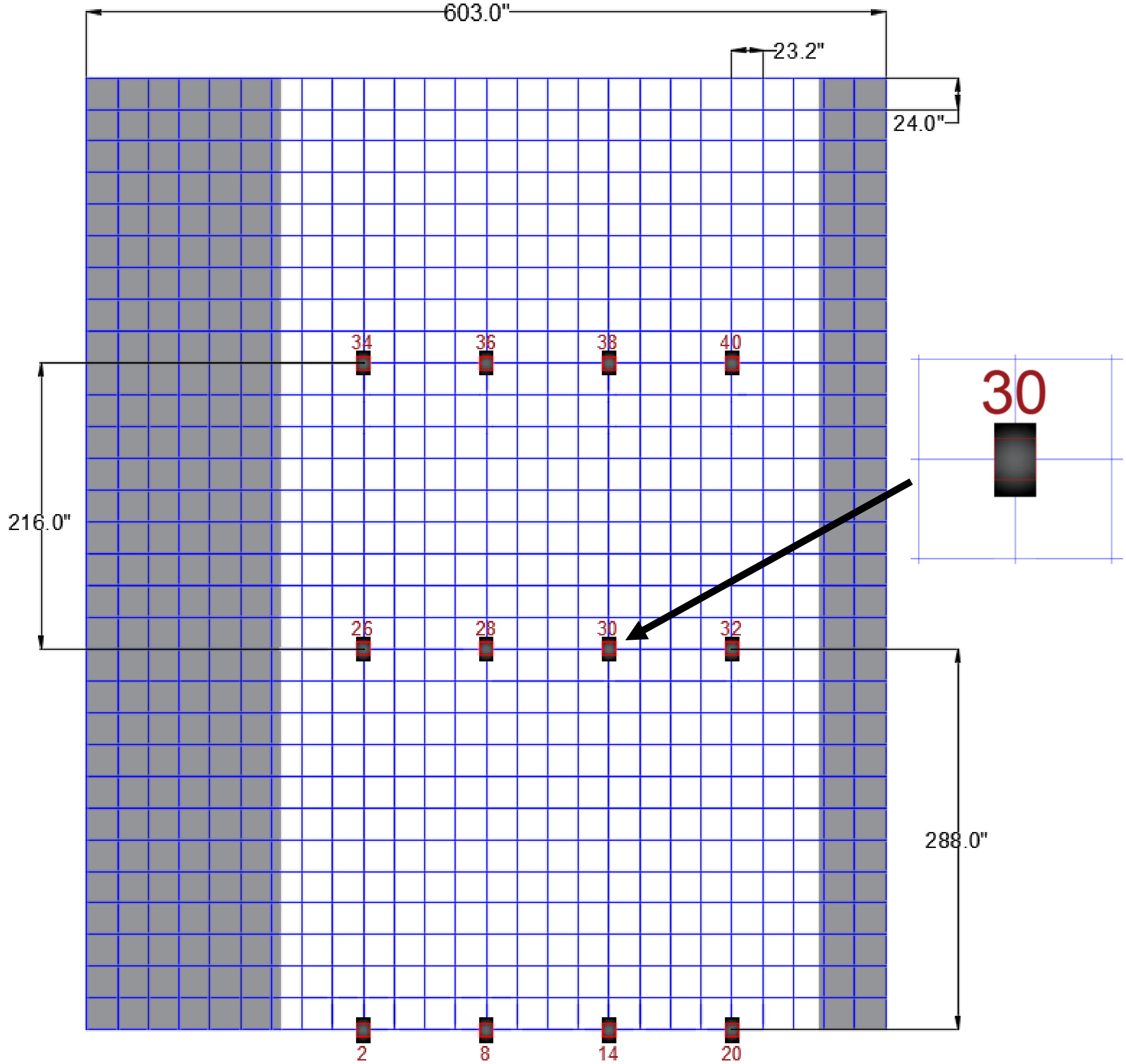


**Figure 27—Position 1 Loading Configuration**

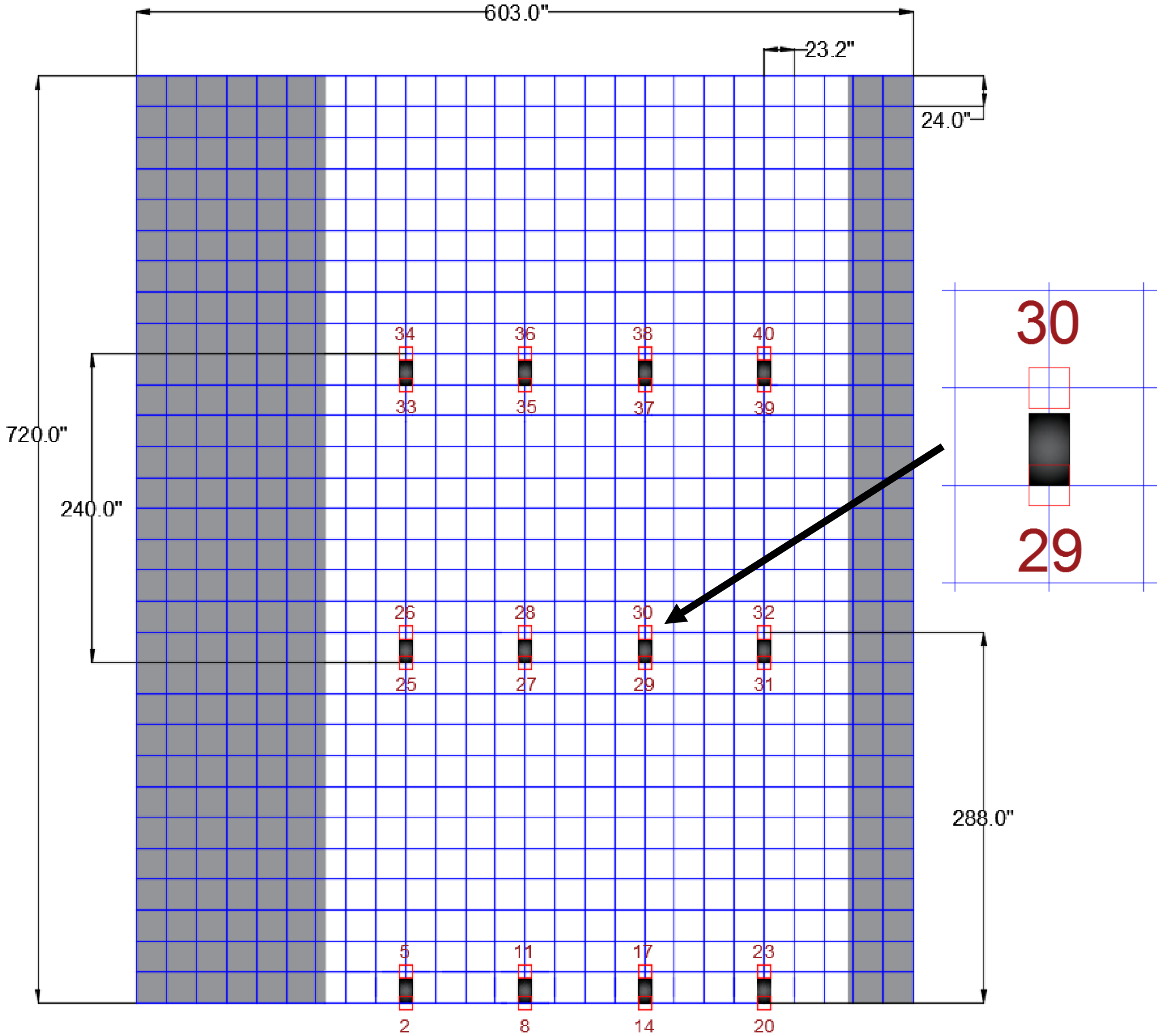


**Figure 28—Position 2 Loading Configuration**

### 5.1.3 | Sensitivity Analysis

Deterioration of bridge elements causes section loss and a decrease in moment of inertia, which in turn has an effect on load rating. According to the GDOT inspection report, some of the beam flanges on the Sanford Drive Bridge have a section loss up to 0.25 in (6.35 mm), and some web faces have a section loss up to 0.50 in (12.7 mm) These conditions and combinations of these conditions were used to determine how the moment demand and shear demand of beam SP7-WF4 changes. Table 13 shows the moment demand based on the equivalent stress results for Position 1 and Position 2. The control case represents the original condition of the bridge with no deterioration. The control moment capacity was found in Table 3-2 of the AISC Steel Construction Manual (13th Edition). The capacity was then adjusted for each deterioration case, and the rating factor was calculated as the moment capacity divided by the moment demand at the center of the beam.

**Table 13—Equivalent Stress Load Rating Results**

| Position | Condition | Moment Demand (k-ft) | | | | | | | Moment Capacity (k-ft) | Rating Factor |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | |
| 1 | Control | 339.4 | 237.2 | 84.7 | 142.0 | 134.8 | 242.7 | 340.9 | 1350 | 9.51 |
| | 1/8” (W) | 323.8 | 226.3 | 80.9 | 135.5 | 128.6 | 231.6 | 325.3 | 1350 | 9.96 |
| | 1/8” ( F) | 323.8 | 226.3 | 80.9 | 135.5 | 128.6 | 231.6 | 325.3 | 1173 | 8.71 |
| | 1/8” (F x2) | 308.0 | 215.2 | 76.9 | 128.8 | 122.3 | 220.2 | 309.4 | 1175 | 9.12 |
| | 1/8” (All) | 292.0 | 204.1 | 72.9 | 122.2 | 116.0 | 208.9 | 293.4 | 1175 | 9.62 |
| | 1/4” (W) | 308.3 | 215.5 | 77.0 | 129.0 | 122.4 | 220.5 | 309.7 | 1350 | 10.47 |
| | 1/4” (F) | 308.2 | 215.4 | 77.0 | 128.9 | 122.4 | 220.4 | 309.6 | 995 | 7.81 |
| | 1/4” (F x2) | 276.0 | 192.9 | 68.9 | 115.5 | 109.6 | 197.4 | 277.3 | 998 | 8.64 |
| | 1/4" (All) | 243.5 | 170.2 | 60.8 | 101.9 | 96.7 | 174.2 | 244.6 | 998 | 9.79 |
| | 1/2” (W) | 277.2 | 193.7 | 69.2 | 115.9 | 110.1 | 198.2 | 278.4 | 1350 | 11.65 |
| 2 | Control | 337.6 | 238.1 | 84.9 | 140.7 | 136.9 | 245.4 | 349.3 | 1350 | 9.59 |
| | 1/8” (W) | 322.2 | 227.2 | 81.0 | 134.2 | 130.6 | 234.2 | 333.2 | 1350 | 10.06 |
| | 1/8” (F) | 322.1 | 227.2 | 81.0 | 134.2 | 130.6 | 234.1 | 333.2 | 1173 | 8.74 |
| | 1/8” (F x2) | 306.3 | 216.1 | 77.0 | 127.7 | 124.2 | 222.7 | 316.9 | 1175 | 9.20 |
| | 1/8” (All) | 290.5 | 204.9 | 73.1 | 121.1 | 117.8 | 211.2 | 300.5 | 1175 | 9.70 |
| | 1/4” (W) | 306.7 | 216.3 | 77.1 | 127.8 | 124.3 | 222.9 | 317.2 | 1350 | 10.56 |
| | 1/4” (F) | 306.6 | 216.2 | 77.1 | 127.8 | 124.3 | 222.8 | 317.2 | 995 | 7.79 |
| | 1/4” (F x2) | 274.6 | 193.7 | 69.1 | 114.4 | 111.3 | 199.6 | 284.1 | 998 | 8.72 |
| | 1/4" (All) | 242.3 | 170.9 | 60.9 | 101.0 | 98.2 | 176.1 | 250.6 | 998 | 9.88 |
| | 1/2” (W) | 275.7 | 194.5 | 69.3 | 114.9 | 111.8 | 200.4 | 285.2 | 1350 | 11.75 |

*W = web, F = bottom flange, F x2 = top and bottom flange*

The same process was used to determine the shear demand based on the maximum shear results for Position 1 and Position 2. The control shear capacity was found in Table 3-6 of the AISC Steel Construction Manual. Table 14 shows the shear demand based on the maximum shear stress results for Position 1 and Position 2.

**Table 14—Maximum Shear Load Rating Results**

| Position | Condition | Shear Demand (k) | | | | | | | Shear Capacity (k) | Rating Factor |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | |
| 1 | Control | 32.7 | 22.4 | 13.4 | 13.4 | 12.7 | 23.2 | 36.2 | 291 | 21.72 |
| | 1/8” (W) | 26.2 | 17.9 | 10.7 | 10.7 | 10.1 | 18.5 | 29.0 | 233 | 21.78 |
| | 1/8” (F) | 32.8 | 22.5 | 13.4 | 13.5 | 12.7 | 23.3 | 36.4 | 292 | 21.63 |
| | 1/8” (F x2) | 33.0 | 22.5 | 13.5 | 13.5 | 12.8 | 23.3 | 36.5 | 293 | 21.70 |
| | 1/8” All | 26.4 | 18.0 | 10.8 | 10.8 | 10.2 | 18.7 | 29.2 | 235 | 21.76 |
| | 1/4” (W) | 19.6 | 13.4 | 8.0 | 8.0 | 7.6 | 13.9 | 21.7 | 175 | 21.88 |
| | 1/4” (F) | 33.0 | 22.5 | 13.5 | 13.5 | 12.8 | 23.3 | 36.5 | 293 | 21.70 |
| | 1/4” (F x2) | 33.2 | 22.7 | 13.6 | 13.6 | 12.9 | 23.5 | 36.7 | 295 | 21.69 |
| | 1/4" All | 19.9 | 13.6 | 8.2 | 8.2 | 7.7 | 14.1 | 22.0 | 177 | 21.59 |
| | 1/2” (W) | 6.5 | 4.5 | 2.7 | 2.7 | 2.5 | 4.6 | 7.2 | 58 | 21.48 |
| 2 | Control | 32.4 | 22.1 | 13.1 | 13.2 | 13.0 | 24.6 | 37.0 | 291 | 22.05 |
| | 1/8” (W) | 25.9 | 17.7 | 10.5 | 10.5 | 10.4 | 19.7 | 29.6 | 233 | 22.19 |
| | 1/8” (F) | 32.5 | 22.2 | 13.1 | 13.2 | 13.1 | 24.7 | 37.2 | 292 | 22.12 |
| | 1/8” (F x2) | 32.6 | 22.3 | 13.2 | 13.2 | 13.1 | 24.7 | 37.3 | 293 | 22.20 |
| | 1/8" All | 26.1 | 17.8 | 10.5 | 10.6 | 10.5 | 19.8 | 29.8 | 235 | 22.17 |
| | 1/4” (W) | 19.4 | 13.3 | 7.8 | 7.9 | 7.8 | 14.7 | 22.2 | 175 | 22.15 |
| | 1/4” (F) | 32.6 | 22.3 | 13.2 | 13.2 | 13.1 | 24.7 | 37.3 | 293 | 22.20 |
| | 1/4” (F x2) | 32.9 | 22.4 | 13.3 | 13.3 | 13.2 | 24.9 | 37.6 | 295 | 22.18 |
| | 1/4" All | 19.7 | 13.5 | 8.0 | 8.0 | 7.9 | 15.0 | 22.5 | 177 | 22.13 |
| | 1/2” (W) | 6.5 | 4.4 | 2.6 | 2.6 | 2.6 | 4.9 | 7.4 | 58 | 22.31 |

*W = web, F = bottom flange, F x2 = top and bottom flange*

### 5.1.4 | Load Rating Summary

Although the bridge superstructure was determined to be in poor condition, this study shows that the structure can still withstand the current bus loading. For both loading positions, all of the rating factors are much greater than 1. Even for all of the deterioration cases, the moment capacity is well above the moment demand. The lowest rating factors for Position 1 and Position 2 based on moment demand were 7.81 and 7.79, respectively. The shear capacity is also sufficient with all of the rating factors near 22.

The influence surface area approach is a beneficial load rating method because it provides the ability to add the load effects from applicable nodes, depending on vehicle positions, after running the finite element model only one time. In this case, the worst case loading condition for the middle span was tested using two different methods of node selection. Once the results have been collected, they can be manipulated to reflect any magnitude of traffic load or loading configuration. This study focused on the loading of UGA Campus Transit buses, but the results could be used to determine rating factors based on different types of traffic loading. Furthermore, the results can be post-processed to account for existing section loss of bridge elements to update a structure's load rating. Therefore, the results collected in this study could be used again to determine the effects of future deterioration.

## 5.2 | E-Construction

The following section includes findings from the e-Construction portion of this study, including information from meetings with various GDOT offices regarding their software usage, communication with internal and external entities, and challenges. This section also includes a draft FHWA AID Demonstration Project Narrative.

### 5.2.1 | GDOT E-Construction Processes

A series of meetings was conducted with GDOT office representatives to investigate the current state of e-Construction at GDOT and to determine how to implement a more efficient program across the entire department. The research team gained an understanding of the needs of each office based on coordination with other GDOT offices and consultants.

#### 5.2.1.1 | Bidding Administration

The Construction Bidding Administration (CBA) is responsible for guiding projects through the Contract Letting Process in accordance with applicable laws and specifications. The office publishes an annual letting schedule for processing projects and prepares bidding proposals. CBA then publishes an advertisement for bid to contractors and requests eligibility to bid. After a list of eligible bidders is published and project amendments have been advertised, the bids are received, processed, and evaluated. Finally, a contractor is awarded, and the contract is processed.

5.2.1.1.1 | *Software*

TPro is the statewide project management database, which is used for reporting and scheduling. Everyone within the department has access to TPro. Program Control determines specific privileges for each office depending on its role. Further, it is possible to have different tiers of access among the same office (ex: Right-of-Way). There are additional stand-alone software programs that are interfaced at the data warehouse, GDOT 411. If someone enters information in TPro, it is automatically updated in other programs through GDOT 411.

Primavera is the software used for project scheduling. Documents are shared through this software, and everyone has access to its content. ProjectWise is used for the approval and distribution of final plans and critical milestones, but not all active files are stored in ProjectWise. Program Control is currently updating the PDP Manual, which is tracked and stored in

ProjectWise. All PDP committee members have access to the software, but there are limitations on who can post and edit documents. Additionally, Microsoft Office applications (SharePoint, etc.) are utilized by Program Control.

5.2.1.1.2 | *Communication*

Program Control is generally on the receiving end of information. Project Delivery is required to report to Program Control and the chief engineer regarding changes in schedule and other critical information. Program Control facilitates monthly status meetings to ensure Project Delivery is on schedule. All offices, including the Office of Construction, are represented at these meetings. Program Control provides project status updates, including changes, risks, and goals. Project status is compared to the baseline schedule, which is based on the approved letting schedule established by the Construction Bidding Administration. Project managers deliver schedule, budget, and invoices. Everyone has access to the P6 schedule, and it is expected to be continually updated.

Currently, about 86% of design projects are conducted by consultants. Consultants have the same expectations and access to software programs as GDOT project managers. The bridge program and traffic operations program are gaining more consultants, while the BFI program has limited consultants. Program Control has no oversight over consultants in other offices.

5.2.1.1.3 | *Challenges*

Project Change Request Forms for schedule changes are now created and approved through SharePoint. They are distributed by the project manager as a PDF to Program Control. The form is then emailed to the director of Program Delivery and the chief engineer. Using SharePoint allows for better tracking of documents, but it is desired for there to be a more efficient long-term solution that can be supported by IT. The processes and policies within Program Control require flexibility. The Office of Program Control receives requests regarding different projects from several different offices, including Program Delivery, Bridge Design and Maintenance, Traffic Operations, and Local Grants. Requests are either sent through email or SharePoint. It would be helpful to be able to organize what requests need to be acted upon. Information that is older than 30 days is lost.

Program Control sees a need for modifications to TPro on the preconstruction side. They are still using paper to print reports, schedules, etc. for status meetings. They could benefit from utilizing monitors, laptops, or tablets to access PDFs during meetings. In addition, it would be helpful to have an automated process for posting reports to reduce the number of emails during concurrent projects. Lastly, real-time information exchange is a challenge for the Office of Program Control. The office distributes information on a monthly basis, while continually working behind the scenes. In order to increase efficiency, the P6 schedule needs to be updated constantly. Although Primavera has the capability of connecting to Outlook, the function is not being utilized.

#### 5.2.1.2 | Bridge Design and Maintenance

The Bridge Design Office is responsible for the hydraulic and structural design of highway bridges, culverts, and retaining walls. The Bridge Maintenance Office conducts inspections of all bridge structures and determines load ratings. In addition, the office designs and details bridge repairs.

##### 5.2.1.2.1 | *Software*

The Bridge Design Office uses MicroStation and in-house software for design. ProjectWise is used for document management and storage. Documents are stored in folders within ProjectWise based on PI number. Additionally, each GDOT office has its own folder. A timestamped, record set of final plans are stored in ProjectWise for bridge projects. Design Policy and Support determines access to the software. At some point, consultants might be granted access to specific project folders. The long-term goal is for everything to be stored in ProjectWise, but documents are still being distributed through email. Bridge Design is in the process of transitioning from hard copies to electronic documentation and developing standardized e-Construction processes.

ProjectWise Deliverables Management is a web-based application that locates files in ProjectWise and uploads them to the cloud for retrieval. It allows for document distribution between GDOT employees and consultants. Design Policy and Support provides ProjectWise training sessions from Bentley staff for both GDOT and its consultants. Bridge Design recently used a project with E.R. Snell as a pilot study for Deliverables Management. Overall, ProjectWise is still only used for document storage.

The Innovative Delivery Office uses e-Builder to manage and store documents for design-build projects in the P3 division. Documents in e-Builder include plans, submittals, shop drawings, and RFIs. E-Builder is highly customized compared to ProjectWise. Bridge Design believes it should be simplified and have improved accessibility.

5.2.1.2.2 | *Communication*

The Bridge Design Office receives requests for bridge design from the project manager or road design engineer through email. The office is working towards providing a PDF version of final plans through a link, which can then be distributed to contractors for bidding. Plans prepared by a consultant must be stamped by that consultant. If the Bridge Design Office creates the plans, the cover sheet is signed by the chief engineer and scanned into the record set plans.

Shop drawings and other submittals are received from contractors through email for quick review and submission. However, these documents are not tracked and can get lost. Shop drawings move between the contractor, the Materials Testing Lab, the area engineer, and others. Plan development documents are distributed to the district Roadway Design Office, OMAT, the Office of Utilities, and sometimes Environmental Services or Right-of-Way. Problems in the field are relayed by phone call or email. Bridge Maintenance is the program manager for bridge projects. Bridge replacements are programmed and then turned over to Program Delivery.

5.2.1.2.3 | *Challenges*

An Encroachment Permit is required to perform work in GDOT right-of-way (ex: bridge over highway). When the district receives a permit, they communicate with the necessary offices through email. These permits, shop drawings, etc. need to be uploaded into ProjectWise, but they do not have a PI number or project manager to correspond to.

Plans often specify for a contractor to design certain components of a project, such as overhead signs, traffic signals, strain poles, and lighting. The contractor sends shop drawings to GDOT for review. These documents often do not have a PI number, so they are managed manually and have no place to be stored. They are scanned and stored in a standalone ProjectWise folder, which is difficult to locate later if change is required.

**5.2.1.3 | Construction**

The Office of Construction is responsible for communicating with the construction industry and developing timely problem resolutions. The office reviews and approves contract modifications and conducts construction compliance audits, project field inspections, and contract compliance investigations.

5.2.1.3.1 | *Software*

The Office of Construction gets involved with a project during the Field Plan Review. The District Offices are involved from the beginning of the process. The Office of Planning, Environmental Services, and Right-of-Way Office currently use ProjectWise for documentation. Their documents are sent to the District Office of Construction. ProjectWise is a secure network for filing contracts and allows a single continuously revised document to be shared. All internal offices have access to ProjectWise; however, some offices are restricted to read-only access, which is controlled by IT. SiteManager is currently employed as a server-based software, but it will be web-based by this time next year. It is used to document daily work reports from the field.

The Contract Authorization Tracking System (CATS) is used for contract modifications. When the Office of Construction receives documents, they mark them up if necessary and provide input through email. Some of these changes are documented on ProjectWise as well. Sometimes other offices will provide a link to the document on ProjectWise through e-mail or provide a hard copy. Payments documented in SiteManager are electronically transferred to Accounting through PeopleSoft. GDOT's Cost Estimation System (CES) is the internal database for estimating. Design Policy and Support is heavily involved with the Office of Construction during preconstruction. During construction, the Office of Construction works closely with OMAT and district offices.

GDOT is currently conducting two project pilots using ProjectWise with contractors. Submittals and other documents are being passed to contractors through the web-based interface and returned to the server. The documents pass through IT security before being transferred. Currently, all field engineers have a tablet for using Bluebeam and other software on site. If service is unavailable in the field, the engineers use their cell phones to retrieve information. Contract liaisons are expected to have tablets by the end of November. The Office of Construction believes there is currently no need for more mobile technology.

5.2.1.3.2 | *Challenges*

Designers are not able to incorporate ideas from the Office of Planning, Environmental Services, and the Right-of-Way Office in their plans. The Office of Construction often does not see documents until something goes wrong and "all easy answers are wrong." Offices involved with preconstruction, consultants, and contractors do not have direct access to ProjectWise. Some

GDOT projects have not been upgraded to electronic document management. By December, GDOT hopes to be using ProjectWise for all projects. Project managers need access to both ProjectWise and SiteManager; however, these programs function separately. Documents are being stored in various locations, and it is difficult for users to know how up-to-date these documents are. Additionally, the Office of Construction is currently unable to respond to emails outside of the office due to a firewall issue.

The Office of Construction suggests it would be beneficial to have an easy way to pull out specific reports from ProjectWise, including a way to download documents from the same contractor across multiple projects. It is critical to the Office of Construction, Financial Management Office, and Bidding Administration to see milestone dates quickly and easily. All documents in the software should be timestamped. The Office of Construction sees a need for more efficient communication between ProjectWise and SiteManager as well as more efficient document transfer among offices. Alternatively, GDOT would benefit from having one central database for document management, such as AASHTOWare. The disadvantage of implementing a new software is the training it would require.

The Office of Construction sees opportunities for new e-Construction innovations in the future, such as e-Ticketing. The overall goal of improving GDOT's e-Construction program is to decrease the amount of time spent on document management and to increase the amount of time spent on quality control.

#### 5.2.1.4 | Design Policy and Support

The Office of Design Policy and Support (ODPS) is composed of three divisions: Engineering Systems Support, Roadway Design Policy, and Location Bureau. Engineering Systems Support is responsible for supporting the department's engineering software systems and visual engineering.

During preconstruction, Roadway Design Policy is responsible for defining and interpreting policy and litigation for roadway design, lighting, and water resources. The division is also responsible for conducting QA/QC of engineering deliverables. The Location Bureau is responsible for statewide aerial mapping and ground surveying. Overall, the office supports and enhances all aspects of program delivery

5.2.1.4.1 | *Software*

The Office of Design Policy and Support supports several programs from Bentley, including ProjectWise, MicroStation, InRoads, OpenRoads, and hydraulics/hydrology software. The office does not support SiteManager.

5.2.1.4.2 | *Engineering Systems Support*

This division coordinates with district IT staff across the state. The frontline support staff handles software installation. Engineering Systems Support also leads document management for the electronic letting process and electronic construction revisions. In the case of a consultant being required to use a specific software, it is up to that consultant to have it.

ProjectWise is a flexible software that allows all files within the department to be centrally located. Some consultants have ProjectWise in their office and can be connected to GDOT project information; however, issues can be encountered if the consultant has a slow connection speed. ProjectWise Deliverables Management, the cloud-based application, is recommended. Deliverables Management improves communication and exchange of data with external consultants. When a consultant uploads a package to Deliverables Management, the receiver at GDOT is notified. The package is electronically reviewed, and the appropriate files are sent back. The consultant will then be notified to download the documents from the cloud.

5.2.1.4.3 | *Roadway Design Policy*

The Roadway Design Policy division is required to communicate with Traffic Operations, Bridge Design and Maintenance, and Roadway Design regarding policy. Questions about deviating from standard policies are directed to Program Delivery or Innovative Delivery. During the conceptual design phase, concept reports are produced and reviewed by the necessary offices. Comments and approvals are provided electronically, and a hard copy of the final report is sent to management.

During construction, the Roadway Policy Group reviews shop drawings for structures that deviate from standard construction drawings. They prepare construction plans for specialty maintenance projects, including erosion control and flooding. The Roadway Lighting Group reviews and approves relevant designs and shop drawings as well. The Water Resources Group manages water quality from concept to letting of the project, coordinating with the Office of Construction.

Once ODPS completes a request, the Office of Construction is responsible for documentation and proceeding. While some PDFs and questions are sent through email, a lot of documentation is distributed as paper copies. These documents could be distributed electronically with ProjectWise Deliverables Management.

5.2.1.4.4 | *Location Bureau*

Aerial mapping and ground surveying information is combined to create 3D models and sent to Roadway Design. The files are uploaded to a folder in ProjectWise, and Roadway Design and the project manager from Program Delivery receive a link to access the documents. GDOT uses a proprietary survey software by Trimble. Consultants might use different survey software than GDOT, but they are still required to provide an InRoads Survey file. If consultants do not have access to ProjectWise, the file is uploaded by the Program Delivery project manager. If the project manager does not have access to the folder, Design Policy provides assistance.

The process could be made quicker if everyone involved had access to the necessary ProjectWise folders. ProjectWise Deliverables Management is currently being tested on a couple pilot projects under construction. Deliverables Management has automated alerts through email and document tracking. The Location Bureau is moving towards requiring external consultants to submit deliverables through this software. In addition, ODPS and consultants are in the process of implementing OpenRoads for designing 3D models.

5.2.1.4.5 | *Challenges*

Older civil design software (e.g. CAiCE) has limited support. The only way to convert projects designed with older software would be to redo all design work.

**5.2.1.5 | Engineering Services**

Engineering Services authorizes Preliminary Engineering (PE), Right-of-Way, and Construction funds and provides project cost estimates. This office reviews plans and facilitates Field Plan Reviews (FPRs). In addition, Engineering Services manages standard specifications and GDOT's Value Engineering Program. They also ensure environmental compliance and conduct Post Construction Evaluations (PCEs). In general, this office oversees federally-funded projects.

5.2.1.5.1 | *Software*

Engineering Services has its own folders within specific project folders in ProjectWise. ES uploads reports to ProjectWise, which are accessed through an emailed link. In the very rare case that a document does not have a PI number, it is emailed as a Word document to the project manager.

Engineering Services receives hard copies of the plan set for reviews (Design Review Section, Preliminary FPR/Final FPR/Corrected Final FPR) and developing an estimate (Estimating

Section, Corrected Final FPR only). In addition, the plans are uploaded to ProjectWise for others to access. Although the district construction offices, district utilities offices, and district environmental offices still receive hard copies, the number of hard copies has decreased to approximately 25% of the number of hard copies from 10+ years ago. However, ES suspects many people who do not receive a hard copy print their own. When consultants perform reviews for Engineering Services, they receive hard copies. ES is moving towards fully implementing electronic document distribution with ProjectWise Deliverables Management. Engineering Services uses TPro, Primavera, and occasionally PCCommon. The office uses e-Builder for Innovative Delivery design-build projects only to compile comments.

Within Engineering Services, documents are shared through network drives. Confidential information from estimators used to develop the Engineer's Estimate is stored here. Engineer's Estimate prices are entered into AASHTO TrnsPort. TrnsPort is also used by Construction Bidding Administration to develop the Letting Proposal and other letting documents. Within TrnsPort, ES can find historical data of final estimates. Within the network, ES can find Excel sheets that were used to build Engineer's Estimates. TrnsPort CES is used to develop the designer cost estimate. AASHTO TrnsPort is becoming an unsupported software, and GDOT is transitioning to AASHTOWare Project.

5.2.1.5.2 | *Communication*

Engineering Services mostly interacts with Program Delivery to facilitate design review meetings, field plan reviews, etc., which are coordinated by the project manager. Engineering Services coordinates with district construction offices through email for coordinating meetings. When the project manager requests a review, they bring a hard copy of the request letter and plans to the Office of Engineering Services. The reviewer emails the project manager, district construction engineer, and designer to determine a date for the review. Once the date is set, a schedule letter is sent through email. A link to the letter and project package in ProjectWise is included in the email. Before the meeting, a draft report with comments is distributed to the team. After the report is reviewed at the meeting, it is distributed through email with the ProjectWise link as well. The designer sends responses through email, and the project manager distributes the report with accepted responses through email and ProjectWise.

5.2.1.5.3 | *Challenges*

The process of assigning reviews to consultants could become more efficient by distributing plans electronically with ProjectWise Deliverables Management. However, some people who review the plans might not have access to a plotter to print them. Many estimators are in Area Offices, and they do not always have the availability to print documents. Overall, Engineering Services sees a lack of knowledge regarding the functionality of ProjectWise. Training was provided for ProjectWise, but it was provided a year or more before it was implemented. Workflows with step-by-step processes are provided online, but not everyone knows they are available.

**5.2.1.6 | Environmental Services**

The Office of Environmental Services (OES) obtains environmental approvals and permits for all projects according to applicable laws, rules, and regulations. The office coordinates with design teams to avoid, minimize, or mitigate harm to the environment. OES identifies environmental resources and assesses project effects to these resources.

5.2.1.6.1 | *Software*

During concept development, OES receives a layout for resource identification from Program Delivery. This document is accessed through a link to ProjectWise, which is sent via email. Folders in ProjectWise are sorted by PI number, and OES has its own folder. The folders are managed by Program Delivery.

Final administrative records are stored in ProjectWise, but it is not usually used for document distribution. Most documents are mailed as hard copies or emailed. If documents need to be sent to outside agencies or if they are too large for email (ex: policy updates, project reports), they are distributed through SharePoint or the FTP site. GIS files slow down ProjectWise, so GIS maps are created outside of the software. A final copy is then saved to ProjectWise. Noise Models cannot be opened in ProjectWise, which complicates the review process if documents are submitted for review through ProjectWise.

PCCommon is a department-wide internal server that is used to share draft documents. PCCommon contains an alphabetical list of files. The framework for TPro was created a decade ago, so it is not structured to meet today's needs. For example, TPro does not have the ability to track permit applications, but SharePoint does. OES needs to be able to track the quality of the documents they are receiving. GDOT's databases do not talk to each other, so it is difficult to ensure everyone has the most up-to-date version of documents throughout the life of a project.

5.2.1.6.2 | *Communication*

Within GDOT, the Office of Environmental Services communicates most often with Roadway Design, Program Delivery, and Innovative Delivery. Additionally, OES communicates with external agencies, such as the US Army Corps of Engineers and the Board of Regents. OES creates a document that publicly discloses the environmental impacts of a project, which is then distributed to FHWA on federally funded projects. The Office of Environmental Services believes they are at 80% of their full e-Construction potential. Some document reviews are still distributed to agencies as hard copies. In terms of signatures, it is mostly a personal preference between electronic signatures and signing a hard copy and scanning the document.

Contractors may make changes during construction, which require them to reapply for permits and surveying. Once a special provision transitions from an environmental commitment to a construction commitment, it may or may not be conveyed properly. The FHWA Georgia Division does not have access to ProjectWise, but they do have access to GeoPI. OES sends FHWA electronic documents, but they print hard copies for archival. Locally, there seems to be a disconnect regarding e-Construction processes.

5.2.1.6.3 | *Challenges*

Document management in ProjectWise requires staff training, and they do not have the time to learn a new software that is not implemented on all projects. They are already updating several databases throughout a project. It is inconvenient to download and re-upload documents in ProjectWise, so it is only used to store final records. In addition, it is difficult to use ProjectWise with documents outside of the PI structure or for external agencies. A lot of processes could probably be automated, but every project is unique. The OES mentioned that it would be ideal to fully implement ProjectWise if it could accommodate all projects and all non-project document coordination.

OES works with multiple outside agencies who have different preferences for processes and document access. The office is moving towards using SharePoint to share documents with consultants. In addition, it is challenging to work with Innovative Delivery because they use e-Builder instead of ProjectWise. Files must be transferred from one software to the other, and people have to be trained before using e-Builder.

#### 5.2.1.7 | Innovative Delivery

The Office of Innovative Delivery is responsible for planning and management of Public-Private Partnerships (P3), Design-Build, and other alternative delivery projects. For these projects, Innovative Delivery conducts the procurement of the contract and becomes the project manager/construction manager until project closeout. P3 projects have different procurement rules, making it a longer process. The procurement of a P3 project typically lasts 18 months compared to 6 months for a regular project. Rigorous document control and confidentiality are important for Best-Value Alternative Technical Concept (ATC) Evaluations.

Innovative Delivery partners with the State Road and Tollway Authority (SRTA) to sign contracts for P3 projects. The contract states that GDOT will fund and manage the project, and SRTA will pay the contractor. Inter-agency relations such as this one require a software that facilitates external communication. The software that Innovative Delivery uses helps reinforce policies and timelines as well as preserve documents.

The number of Innovative Delivery contracts per year varies since there is no quota. Overall, it is a small percentage of GDOT projects. Over the last 10 years, the average contract value of Innovative Delivery projects is $100 million per year. Currently, there is $2 billion worth of Innovative Delivery projects under construction, with even more in the preconstruction phase.

##### 5.2.1.7.1 | *Software*

The Office of Innovative Delivery uses TPro for preconstruction information and Primavera for project scheduling. Innovative Delivery retrieves concept reports from ProjectWise. SiteManager is used for standard pay request processes. SharePoint is used to share Reference Information Documents outside of contracts with proposers. Requests for Proposal are posted on SharePoint as well. Assure-IT by Aster is used for material testing data. Innovative Delivery uses CATS to process agreements, following legal financial steps. A modification was added to CATS to replace manual routing of contracts with external agencies (FHWA, contractors, etc.). DocuSign is used in conjunction with CATS for e-signatures. Contracts with SRTA are created in e-Builder.

The Office of Innovative Delivery acquired an unlimited license for e-Builder in 2012 or 2013. It is used to distribute, review/approve, and store documents, including submittals, RFIs, and pay requests. Processes within e-Builder are customizable. The software audits all processes by tracking ball-in-court, user comments, when documents are approved, and who approved them. In addition, Innovative Delivery can see statistics from the software, including information about its users. Customized access can be created for contractors. Innovative Delivery is not currently using all of e-Builder’s capabilities. Innovative Delivery has enhanced its e-Builder license to interface the software with Primavera. However, e-Builder is not connected to PeopleSoft or TPro.

Approximately 4,000 submittals have been completed in e-Builder to date. The software was purchased in order to avoid having to hire more people to manage documents. It was selected with adaptability and scalability in mind. The Program Manager provides training for e-Builder.

5.2.1.7.2 | *Communication*

Concept reports are processed the same way as any other project. They are submitted to Design Policy and Support and distributed electronically through ProjectWise. Concept reports can be signed electronically. The ATC process often involves review, comments, and approval from Bridge Design personnel, so they have access to e-Builder.

5.2.1.7.3 | *Challenges*

E-Builder does have some querying capabilities, but it usually requires going into the file structure. The software is not compatible for uploading material testing data. Innovative Delivery is currently working with OMAT to solve this issue. OMAT favors using Assure-IT for material certifications.

The software allows certifications to be completed every 3 months throughout a project, which shortens the time to finish certifications after project completion. The software is customizable, which is beneficial for materials quality assurance and Design-Build projects. Innovative Delivery projects usually have a large amount of material being tested by a complex team. Material test data can be entered into Assure-IT in the field, and it is integrated and organized into the software. The software can be used for materials document management and as a repository. E-Builder and Assure-IT do not feed information to each other. E-Builder has the documents, but it does not have all the data required for analysis and decision-making. Innovative Delivery is not currently creating 3D models. The office creates 2D plans, which are then converted to 3D models.

While some processes for submittal tracking has been implemented in ProjectWise, the functionality of ProjectWise does not match that of e-Builder. The department could benefit from using e-Builder (or a similar software) to create standardized processes for all project managers. E-Builder can be viewed as a tool for submittal management, which is extremely important for Innovative Delivery projects. New processes can be tested in e-Builder without interfering with the rest of the department.

**5.2.1.8 | IT Application Support**

The IT Application Support Office is composed of two divisions: Applications Development and Applications Support. The Development Division manages the development of new applications and coordinates the department's Geographic Information System (GIS). The Support Division maintains the department's computer applications and shared resources to support the Plan Development Process. IT Application Support is responsible for the historical archiving and retention of records. This office is the contact for application troubleshooting, end-user access, and other user needs.

5.2.1.8.1 | *Software*

Applications that are supported by this office include TPro, Primavera, SiteManager, and ProjectWise. Support for ProjectWise is provided by the engineering support team throughout construction. Data is made accessible online for those who do not have access to ProjectWise. Additionally, plans reflecting the latest revisions are available on GeoPI. ProjectWise contains information from TPro through the use of metadata. IT Application Support suggests focusing less on the folder structure of ProjectWise and more on using metadata for searching and retrieving documents. There are too many folders within ProjectWise, and it is up to the user to determine if documents are in the right folder and who has access to these folders. It was suggested that files be stored in a manner in which the information could be more easily queried. Design Policy approves public access to the software.

The Primavera P6 software has not been changed since it was received from the vendor, and it is not being used to its full advantage. SiteManager is an AASHTOWare software with modules for preconstruction, bidding (Expedite), civil rights and labor management, construction, and materials and testing. This software is primarily used by the Office of Construction, and other offices pull information as needed. IT Application Support created the standardization of project IDs. Additionally, the office has worked to create interoperability among TPro and AASHTOWare TrnsPort.

5.2.1.8.2 | *Challenges*

There are some gaps in the coordination of applications. For example, design-build P3 projects are performed by consultants and are not part of GDOT’s internal system. Consultants do not use the same technology as GDOT, so their projects are managed outside of the department. For example, while GDOT moved to Primavera, the P3 division uses e-Builder. Data is transferred to GDOT information systems and vice versa.

PeopleSoft is used as the financial record system within the state of Georgia. IT Application Support has not been given approval to have direct access to PeopleSoft. FAO provides IT with financial data to be recorded in GDOT's database. GDOT inputs a large amount of data into PeopleSoft, and it does not always make it back to the database. If IT Application Support did receive all of the necessary information, more extensive financial analysis could be conducted. It would also improve synchronization with the project programming software, TPro. IT Application Support is currently working with GoldenGate to improve data integration.

IT Application Support fulfills the business needs of GDOT. Although IT does not actively look for inefficiencies, they believe processes could be simplified by workflows. Bridge Design, for example, is starting to implement workflows to help route documents to the appropriate individuals for review, approval, and acceptance of contracts and permits. Documents in ProjectWise with the correct metadata can be pulled by IT and shared with other applications. Some information is duplicated on SharePoint and ProjectWise. GDOT 411 is a separate reporting function used to access information. Oracle Business Intelligence Enterprise Edition (OBIEE) also has reporting capabilities. After updates, OBIEE will be able to support Primavera reporting and PeopleSoft data. At this point, there are two separate instances of data.

#### 5.2.1.9 | IT Infrastructure

The IT Infrastructure Office is responsible for the operation and management of the department's computer hardware and software. The office consists of Database Support, Server Support, Network Support, Client Support, and the Solutions Center. IT Infrastructure deals with domain information, security, firewall protection, internet proxy work, support and maintenance to all end devices (printers, computers, etc.), and quality assurance for applications developed internally. The office maintains a data repository for all department software purchases and site licenses. IT Infrastructure backs up all of GDOT's software data.

5.2.1.9.1 | *Software*

IT Infrastructure provides back-end support for the GIS application but does not deal with the application's functionality. The Office of Design Policy and Support manages the implementation of ProjectWise. GDOT offices reach out to IT Infrastructure to request external access to applications. IT can either publish web-based applications externally or provide VPN access for external agencies, depending on what the office is comfortable with and what the technology will support. A routine audit validates all external accounts.

IT is always looking for ways to reduce the number of applications within the department. The number of applications has dropped to about 65% of the amount in use 10 years ago. GDOT's internal data warehouse has access to the information within TPro, PeopleSoft, and other applications. GDOT 411 pulls data from the warehouse to be shared across applications. The implementation of e-Builder was more of an add-on than an integration.

IT Infrastructure is involved with providing connectivity to remote sites. The office conducts testing and routing of devices when a vendor installs them. IT Infrastructure took care of everything from a hardware standpoint for field applications. The office participated in the selection of laptops and tablets and the creation of hotspots. Last year, IT Infrastructure conducted a pilot study with construction engineers and different types of devices (Surface Pro, Apple). From a field perspective, usability was the main concern, including screen brightness, ruggedness, and connectivity via 4G or hotspots. Cost was taken into account as well.

PCCommon is the only network share location that everyone in the department can access. Every office and each individual has his or her own folder within PCCommon. It is considered an easy way to share information, since permission is not required for access. However, several offices use SharePoint instead to share documents internally and externally in order to have more control/protection over information. PCCommon is not managed, and IT does not guarantee that files will not be deleted.

Workflows have been created in Remedy, SharePoint, and ProjectWise. IT Infrastructure uses Remedy, a ticketing system, to track tasks. Offices can send a ticket request to IT Infrastructure through Remedy that can be picked up by an employee and closed out when it is complete. The system keeps a record of tasks, how long it took to complete each task, and when each task was completed. Human Resources, Procurement, Customer Service, and executives use Remedy as well.

5.2.1.9.2 | *Challenges*

Devices have been provided for those in the field, but it is difficult to keep up with advancements in technology. In addition, document sharing internally and externally is a challenge. Every entity has their own cloud storage (iCloud, Dropbox, etc.). Having files in several different locations makes document management difficult. Finally, the local area networks available to district offices do not always have the connectivity required to support the use of document management through ProjectWise.

**5.2.1.10 | Materials and Testing**

The Office of Materials and Testing (OMAT) provides expertise and testing for materials used in construction and maintenance projects. In addition, OMAT manages the qualified products list, specifies material requirements, and provides geotechnical services.

5.2.1.10.1 | *Software*

During preconstruction, OMAT is involved with concepts and preliminary field plan reviews. This includes payment evaluations and site reports. Currently, pavement evaluations are electronically submitted and reviewed through ProjectWise. The approved report is distributed through an emailed link. OMAT is working towards electronically processing reports for geotechnical applications as well, including soil surveys, retaining walls, and bridge foundation investigations (BFIs). In the bidding phase, material testing is requested from the field. These test reports are conducted through 411, and there is no physical delivery of these documents. In addition, field auditing is an electronic process. Everything is reviewed through email and ProjectWise. Both pavement evaluations and material certifications use electronic signatures.

The software utilized in the preconstruction phase includes internal software for payment evaluation and others for geotechnical applications. SiteManager Materials (LIMS) contains all material data. However, raw data cannot be retrieved from SiteManager directly. Reports are created through 411 and are distributed through an automated email to individuals from the area office. The reports are only created for completed samples, so there is no issue of having duplicate versions or not having the most up-to-date report.

Currently, tonnage for concrete and asphalt based on plant production is recorded in SiteManager Materials. Actual tonnage and pay items for these materials are recorded in SiteManager Construction. Overall, the pay quantity in SiteManager Construction should not exceed the value in SiteManager Materials. Daily work reports for material temperature, time of truck arrival, etc. are entered in SiteManager Construction. Materials certificates recently started being saved in ProjectWise. Moving forward, documents for all new projects will be stored in ProjectWise. Information in SiteManager Materials is not duplicated in ProjectWise.

Each unit (testing management, geotechnical, pavement, etc.) has their own access to relevant information in ProjectWise and SiteManager. Access is not restricted to only that folder. The software has a tracking component, so it records who adds or deletes a document or where a document has been moved. Vendors and consultants of contractors have the same access to their project on the software. GDOT consultants see the same information as a GDOT employee. OMAT is an advocate for an increased use of ProjectWise throughout all GDOT offices. OMAT estimates it is at 35% of its full e-Construction capability.

5.2.1.10.2 | *Communication*

The Office of Materials communicates through district construction personnel. This communication is usually through email or hand delivery of a sample card rather than through ProjectWise. OMAT only contacts personnel from the Office of Construction (John Hancock, Beau Quarles) if there is an issue in the field. Technical Assistance Bureau requests come in through email, and OMAT responds through email. Waivers are saved in an electronic folder. It is assumed that the district has been uploading information to ProjectWise since December 2017.

5.2.1.10.3 | *Challenges*

The Office of Materials is interested in e-Ticketing, but more research should be conducted prior to implementation. In addition, OMAT is working towards implementing an electronic process for tagging concrete cylinders. This process, also known as e-Tagging, will timestamp each cylinder with a barcode to specify break times. Construction personnel will use a hand scanner to create the barcode, and lab personnel will then scan the code at the lab. GDOT’s IT Office is currently working on the script and looking at a third party software. OMAT is currently using sample cards for materials in the lab, but they are interested in implementing an electronic process for material samples (similar to e-Tagging).

GDOT has not yet moved to the web-based version (3.18) of SiteManager, and the current version is not user-friendly. There are many steps required to input information. Additionally, OMAT heavily relies on IT to create 411 reports. The reports are auto-generated and distributed to people who might not be interested in seeing the report. Geotechnical processes are currently being refined. They will no longer do paper reviews after they get tablets and monitors. OMAT would like full electronic submission, review, and approval of all submittals (Primavera P6 activity schedules) from project management side during preconstruction using ProjectWise. These submittals are needed to finalize bids and will help with OMAT performance metrics. It would be helpful to have all documentation from older projects in an electronic format so everyone can have access.

#### 5.2.1.11 | Planning

The Planning Office manages the state transportation planning program. The office is responsible for developing the Statewide Transportation Plan (SWTP), State Transportation Improvement Program (STIP), Statewide Strategic Transportation Plan (SSTP), Congestion and Mitigation/Air Quality (CMAQ) coordination, and Scenic Byways Program.

##### 5.2.1.11.1 | *Software*

The Office of Planning has its own folder in ProjectWise. Historical data and planning studies can be stored here, but currently this is not common practice. The office is working to develop a planning package that can be sent electronically to Program Delivery and stored in ProjectWise based on PI number. Once a project has a PI number, there are standard practices for other offices. Documents are transferred from the internal server to ProjectWise by other offices. Overall, the Office of Planning uses ProjectWise as a central location for project information for the department to access.

For cost estimating, the Office of Planning uses a tool that is an extension of the AASHTO Cost Estimation System (CES) or the Right of Way and Utility Relocation Cost Estimate Tool. There is a handbook for these estimating tools in the office. A statewide travel demand model is used to assist MPOs with estimation of future travel demand as well as provide the ability to test various project alternatives.

5.2.1.11.2 | *Communication*

The Office of Planning is responsible for acquiring additional funding outside of PE funding, ROW funding, and construction funding. The project manager sends documents for initiation to the Office of Planning through email, and responses are distributed electronically. The Office of Planning primarily communicates with the Office of Financial Management, Program Delivery, and Innovative Delivery. Concept reports from Innovative Delivery are reviewed by the Office of Planning. Attachments are sent through email to the project manager. Externally, the Office of Planning communicates with Metropolitan Planning Organizations (MPOs). External organizations have access to project information through GeoPI.

The Office of Planning sends an initial cost estimate to Financial Management to receive funding and a PI number for the project. This communication is through email, and a copy of the documentation is stored on an internal department-wide server. If everything goes as planned, there is no communication between the Office of Planning and Construction after a project is let. The only interaction Planning might have with the Office of Construction is in regards to CEI funding, which is not project specific. Questions from the public are directed the project manager.

5.2.1.11.3 | *Challenges*

Within the Office of Planning, a lot of data is generated prior to a project receiving a PI number. If a project does not have a PI number, the corresponding documents are labeled with the county or state route name.

**5.2.1.12 | Program Control**

The Office of Program Control monitors, controls, and reports on project status. The office houses the department's project scheduling software and project status reports. The Program Control Office leads the PDP training course and the Local Administered Project training, emphasizing the importance of collaboration. Additionally, Program Control maintains a balanced Construction Work Program, providing monthly letting list recommendations, and reviews project concept reports.

5.2.1.12.1 | *Software*

TPro is the statewide project management database, which is used for reporting and scheduling. Everyone within the department has access to TPro. Program Control determines specific privileges for each office depending on its role. Further, it is possible to have different tiers of access among the same office (ex: Right-of-Way). There are additional stand-alone software programs that are interfaced at the data warehouse, GDOT 411. If someone enters information in TPro, it is automatically updated in other programs through GDOT 411.

Primavera is the software used for project scheduling. Documents are shared through this software, and everyone has access to its content. ProjectWise is used for the approval and distribution of final plans and critical milestones, but not all active files are stored in ProjectWise. Program Control is currently updating the PDP Manual, which is tracked and stored in ProjectWise. All PDP committee members have access to the software, but there are limitations on who can post and edit documents. Additionally, Microsoft Office applications (SharePoint, etc.) are utilized by Program Control.

5.2.1.12.2 | *Communication*

Program Control is generally on the receiving end of information. Project Delivery is required to report to Program Control and the chief engineer regarding changes in schedule and other critical information. Program Control facilitates monthly status meetings to ensure Project Delivery is on schedule. All offices, including the Office of Construction, are represented at these meetings. Program Control provides project status updates, including changes, risks, and goals. Project status is compared to the baseline schedule, which is based on the approved letting schedule established by the Construction Bidding Administration. Project managers deliver schedule, budget, and invoices. Everyone has access to the P6 schedule, and it is expected to be continually updated.

Currently, about 86% of design projects are conducted by consultants. Consultants have the same expectations and access to software programs as GDOT project managers. The bridge program and traffic operations program are gaining more consultants, while the BFI program has limited consultants. Program Control has no oversight over consultants in other offices.

5.2.1.12.3 | *Challenges*

Project Change Request Forms for schedule changes are now created and approved through SharePoint. They are distributed by the project manager as a PDF to Program Control. The form is then emailed to the director of Program Delivery and the chief engineer. Using SharePoint allows for better tracking of documents, but it is desired for there to be a more efficient long-term solution that can be supported by IT. The processes and policies within Program Control require flexibility. The Office of Program Control receives requests regarding different projects from several different offices, including Program Delivery, Bridge Design and Maintenance, Traffic Operations, and

Local Grants. Requests are either sent through email or SharePoint. It would be helpful to be able to organize what requests need to be acted upon. Information that is older than 30 days is lost.

Program Control sees a need for modifications to TPro on the preconstruction side. They are still using paper to print reports, schedules, etc. for status meetings. They could benefit from utilizing monitors, laptops, or tablets to access PDFs during meetings. In addition, it would be helpful to have an automated process for posting reports to reduce the number of emails during concurrent projects. Lastly, real-time information exchange is a challenge for the Office of Program Control. The office distributes information on a monthly basis, while continually working behind the scenes. In order to increase efficiency, the P6 schedule needs to be updated constantly. Although Primavera has the capability of connecting to Outlook, the function is not being utilized.

**5.2.1.13 | Program Delivery**

The Office Program Delivery (OPD) communicates with department offices, metropolitan planning organization (MPO) staff, local government, business, and community stakeholders, and other government agencies to ensure effective project development and delivery. Project managers within Program Delivery are responsible for critical project delivery tasks, including scope, schedule, budget development, resource management, and risk analysis.

5.2.1.13.1 | *Software*

The Office of Program Delivery uses ProjectWise as a centralized server system for document management and storage. Documents related to in-house projects have been migrated from other server sources to ProjectWise, and documents related to consultant projects are currently being migrated. Documentation for new projects moving forward will be stored on ProjectWise, but historical data is not. Since the data migration process is ongoing, Program Delivery has not yet explored the full functionality of ProjectWise. The office estimates it will be using ProjectWise on a broader level in preconstruction within another year and a half. The construction staff have tablets with access to ProjectWise but are still being trained on how to access files. The Office of Program Delivery communicates with external entities that do not have access to ProjectWise. PDF documents from ProjectWise are shared externally on GeoPI. OPD does not plan to use e-Builder outside of Innovative Delivery projects.

Additional software programs used by Program Delivery include cost estimating software, invoicing software, Remedy, Microsoft Office products, Primavera P6, and TPro 4.01. Primavera is used for scheduling. TPro is used to store data in a way that allows OPD to conduct queries. The new version, TPro 5.0, will allow data to be linked together in a centralized system for more efficient reporting. Pre-let data is stored in Primavera, TPro, and MS Word and Excel documents. The software programs communicate well, but there are not enough modules within TPro for proper query and data storage. OPD has made a request to IT to update TPro with additional modules. The Office of Program Delivery would like the ability to use TPro for additional tasks. For example, tasks that might be of interest include: looking up projects that are within a mile from an airport, searching for documents associated with the Corps of Engineers, and looking up data associated with an individual regardless of consulting firm.

The Office of Program Delivery prefers to have some level of redundancy for safety of documents. Since ProjectWise is not able to run queries, OPD considers ProjectWise to be a backup to TPro. Each office has their own TPro modules, and project managers can query this information. GDOT 411 is the querying software across all metadata from TPro, Primavera, etc., which allows the creation of customized reports.

5.2.1.13.2 | *Communication*

ProjectWise is used for document distribution as well. Program Delivery includes a ProjectWise link in transmittal letters and links in emails to let people know information is available for retrieval. OPD does not want the system to notify people automatically because they conduct quality control checks on product information, field plan reviews, etc. The Office of Program Delivery encourages other offices to save information in ProjectWise.

OPD usually sends consultants to GeoPI for project budget information, scheduling information, and status reports. The office controls what information is available externally, which does not include draft documents. Review agencies, such as the Corps of Engineers, usually want hard copies and send back hard copies of approvals. Larger documents are distributed to consultants through email or the FTP site.

5.2.1.13.3 | *Challenges*

Oftentimes it is easier to distribute documents through email because people are not always comfortable using a dashboard like ProjectWise.

**5.2.1.14 | Roadway Design**

The Office of Roadway Design is responsible for the design of state transportation projects, including the development of conceptual layouts, preliminary and final construction plans, and right-of-way plans. This office focuses on quality assurance, quality control, and consultant oversight.

5.2.1.14.1 | *Software*

The design software used by the Office of Roadway Design is InRoads with Bentley MicroStation used for drafting. ProjectWise is used office-wide as a document management and distribution system for PDFs. For example, final plans are posted in ProjectWise, and a link is emailed to those who need access. The following categories have a folder in ProjectWise: environmental surveys, concept reports, geometry, quality assurance, preliminary field plan review, ROW plans, final field plan review, permitting, and letting plans. Plan sets are printed, and the cover sheet is signed one time by the chief engineer.

Specified user groups have different privileges to access folders in ProjectWise. These groups are determined by Design Policy and must be established each time GDOT has a new consultant. In some cases, however, other people might be interested in looking at documents, such as submittals. An original copy of each document is stored separately in case something is modified or deleted. ProjectWise is occasionally used for historical plans research. The Office of Roadway Design supports the use ProjectWise as a department-wide document management system. Unfortunately, some offices are not currently taking advantage of the software's full potential. The Office of Roadway Design does not work with SiteManager. Although they are using components of e-Construction, such as PDFs and emails, they believe there is room for improvement.

By January 1, 2019, the Office of Roadway Design plans to provide contractors with pre-bid models electronically. Roadway Design or the district design office currently does 3D modeling to replace cross-sections, but the software is not being used to its full advantage. This new process is expected to reduce cost, eliminate risk, and increase trust in plans.

5.2.1.14.2 | *Communication*

Before a project is awarded, the Office of Roadway Design communicates with the Office of Construction and the Construction Bidding Administration. During construction, Roadway Design communicates with both the state Office of Construction and District Construction Offices. In addition, they receive questions from the contractor through phone call or email. Field conditions might lead to a request for evaluation of design or redesign. Post-construction, there is communication between the District Office liaison, project manager, and construction engineer through email and phone calls.

5.2.1.14.3 | *Challenges*

Generally, Roadway Design does not have issues with document transfer due to the folder structure and milestone tracking in ProjectWise. There are duplicate files of concept reports, final plans, etc., but they are meant to document changes during design. For the most part, ProjectWise eliminates the mistake of looking at the wrong version of a document.

One challenge Roadway Design faces is resolving problems in the field as quickly as possible. Oftentimes, this process requires coordination with several different offices, while being filtered through the project manager. It can be difficult to determine who is responsible for what. The design team might be working on a solution, while people in the field have not received any updates.

**5.2.1.15 | Right-of-Way**

The Office of Right-of-Way (ROW) acquires the property necessary for transportation projects. This office is responsible for design review and approval of plans, appraisals, relocation assistance, condemnation, negotiation, and property management.

5.2.1.15.1 | *Software*

TPro is the database used to store right-of-way data and track property disposals. The database can be used to run queries, and it is tailored for specific right-of-way tasks (relocation packages, appraisals, condemnation, etc.). Other software programs used by the Office of Right-of-Way include ProjectWise, e-Builder, PeopleSoft, the file transfer site, and GeoPI. ProjectWise is used for document storage. PCCommon and SharePoint are used to share documents with other offices.

GDOT 411 is a database that stores data from TPro but not ProjectWise and provides querying capabilities.

ROW plans are submitted to the Office of Right-of-Way electronically through ProjectWise. The plans are reviewed on Bluebeam, and the office communicates through email and ProjectWise regarding corrections. The plans are then approved in ProjectWise. After ROW plans are approved, the ROW authorization process begins. A hard copy of Form 1625 is sent to the Office of Financial Management for final approval. Although ROW still communicates through email, documents are always stored and accessed through ProjectWise. Projects that do not have a PI number are assigned a number beginning with H. Those ROW files are stored on a CD. All new projects that come to the Right-of-Way Office now have PI numbers.

When the Office of Right-of-Way receives ROW plans, the project is assigned to a district ROW team manager. All activities and acquired assets are tracked in TPro. It shows timelines for appraisals as well. TPro is a comprehensive database for storing metadata, while ProjectWise is a storage unit. ProjectWise is not able to run queries. Innovative Delivery projects are still documented in TPro, but they also require the use of e-Builder internally and externally. E-Builder is even more comprehensive and captures great detail. However, it does not track all milestones in the parcel acquisition life cycle. E-builder requires TPro, but TPro does not require e-Builder. HNTB provided the Office of Right-of-Way with a flowchart explaining the functionality of e-Builder. The district ROW offices do not use e-Builder because they are not usually involved with design-build projects.

The Office of Right-of-Way requests checks and financial information through PeopleSoft, the state accounting system. Few people in the Right-of-Way Office work with this program. CATS is the software used to route contracts and documents that require a commissioner's signature, such as deeds. CATS only tracks signatures, so the documents are still kept as hard copies. Team Market Place is where supplies are ordered.

The Office of Right-of-Way is working towards using ArcGIS as an interactive system for all state and federal routes. The office is working with IT and Arcadis to make a comprehensive program that can be used with Citrix. A consultant helped the office plot all parcels. It would be ideal to have TPro interfaced with the new GIS software.

5.2.1.15.2 | *Communication*

The Office of Right-of-Way communicates with Program Delivery, Innovative Delivery, Environmental Services, and the district Right-of-Way teams (which are extensions of the ROW Office). Consultants do not currently have access to TPro or Deed Writer. The Office of Environmental Services is running a pilot to test consultant access to TPro. The Office of Right-of-Way uses SharePoint or the FTP site to share large files with consultants. Design Policy is currently going through the process of providing consultants in each office with access to ProjectWise.

5.2.1.15.3 | *Challenges*

The Office of Right-of-Way feels they are using too many applications with overlapping capabilities. Every time a new program is implemented, everyone has to be trained, including people in the district offices. Training for ProjectWise was provided six months before it was implemented. There is a lot of repetition of documents, and processes could be automated. One solution is to implement one central software that combines the capabilities of ProjectWise, TPro, and e-Builder. Another solution would be to continue using TPro and have it interfaced with ProjectWise and other software programs. It is possible that the software solution for GDOT is to establish better interfaces rather than implementing one overarching software. Offices are more comfortable using their own software.

### 5.2.2 | GDOT Software Usage and Challenges

Based on the information collected in the meetings, two diagrams were created to illustrate GDOT's construction administration software usage. The first illustration is a web-based, interactive mapping tool displaying GDOT's software usage in relation to office, project phase, and task. The diagram includes all of the offices that were interviewed as well as all of the software programs that were discussed. These software programs were then connected to corresponding tasks and phases of construction (Programming and Scheduling, Concept Stage, Preliminary Design, Final Design, and Construction Phase). This mapping tool allows the user to scroll over any item and view the connections among each category. This tool is helpful in determining what software programs are used the most by the department and which ones have overlapping capabilities. For example, Figure 29 shows the connections that are displayed when "ProjectWise" is selected. As the diagram shows, ProjectWise is used by almost every office during all phases of construction. As another example, Figure 30 shows the connections that are displayed when the task "Share Documents Externally" is selected. The diagram shows that four different software programs are used by various GDOT offices to share documents with consultants, contractors, and other external agencies. This shows inconsistency among offices and might suggest that some of these programs are unnecessary. This mapping tool can be continually updated to reflect any changes GDOT makes to its e-Construction processes.

The second illustration, shown in Figure 31, is a mapping diagram displaying GDOT's software usage in relation to office and task. The inner level contains the software programs mentioned in the meetings. The middle level shows the offices that use each program, and the outer level shows what tasks they are used for. The size of each colored sections shows how common each software program is among the offices that were interviewed. Again, ProjectWise is the most commonly used software. SiteManager, TPro, Primavera, GDOT 411, GeoPI, CES, SharePoint, and CATS are other common programs. Although the diagram shows that e-Builder is used just as often as the previous programs, it is only used for Innovative Delivery projects. Appendix A shows larger versions of the interactive mapping tool and the mapping diagram.

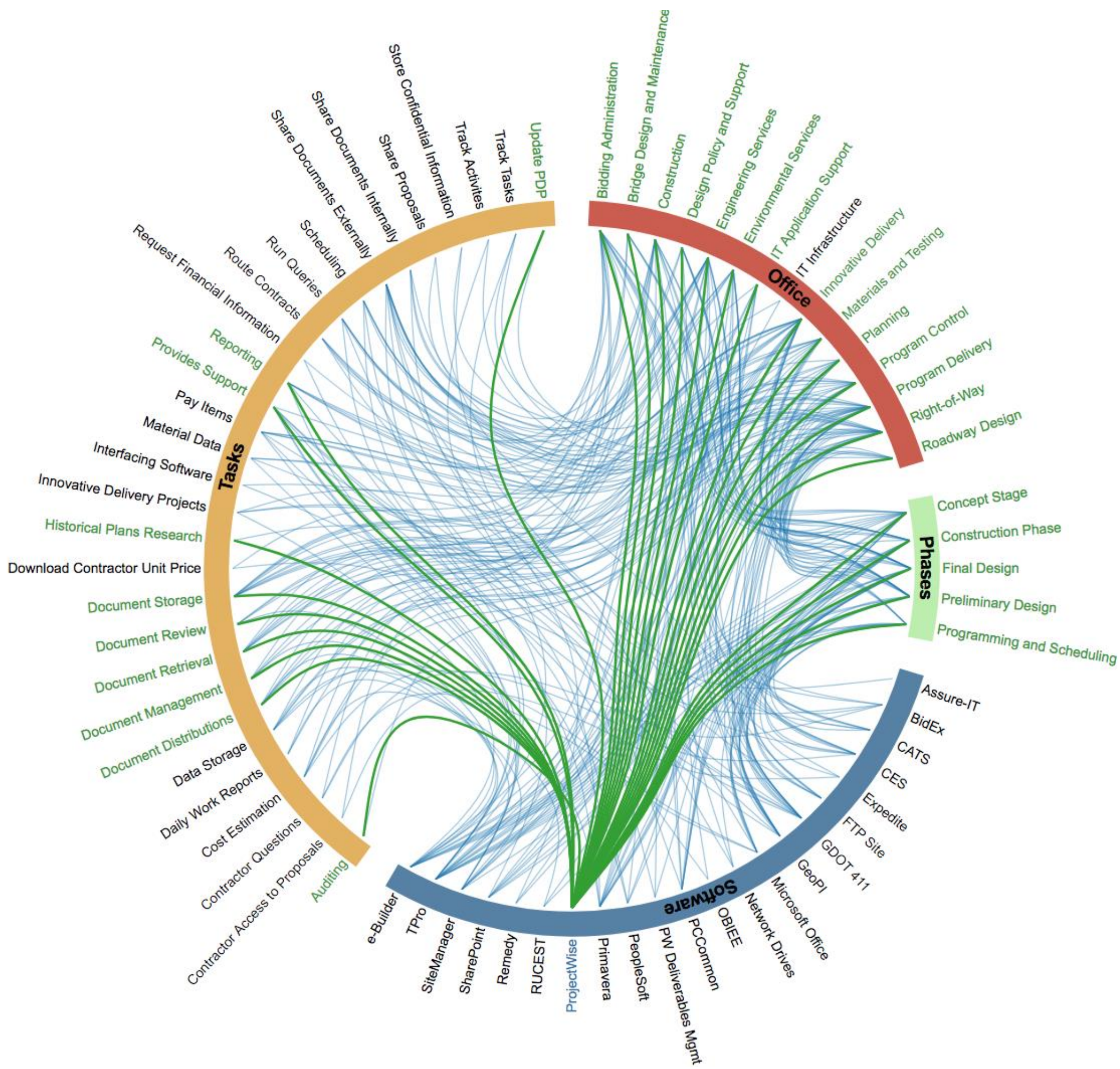


**Figure 29—Interactive Mapping Tool of GDOT Software Usage (ProjectWise)**

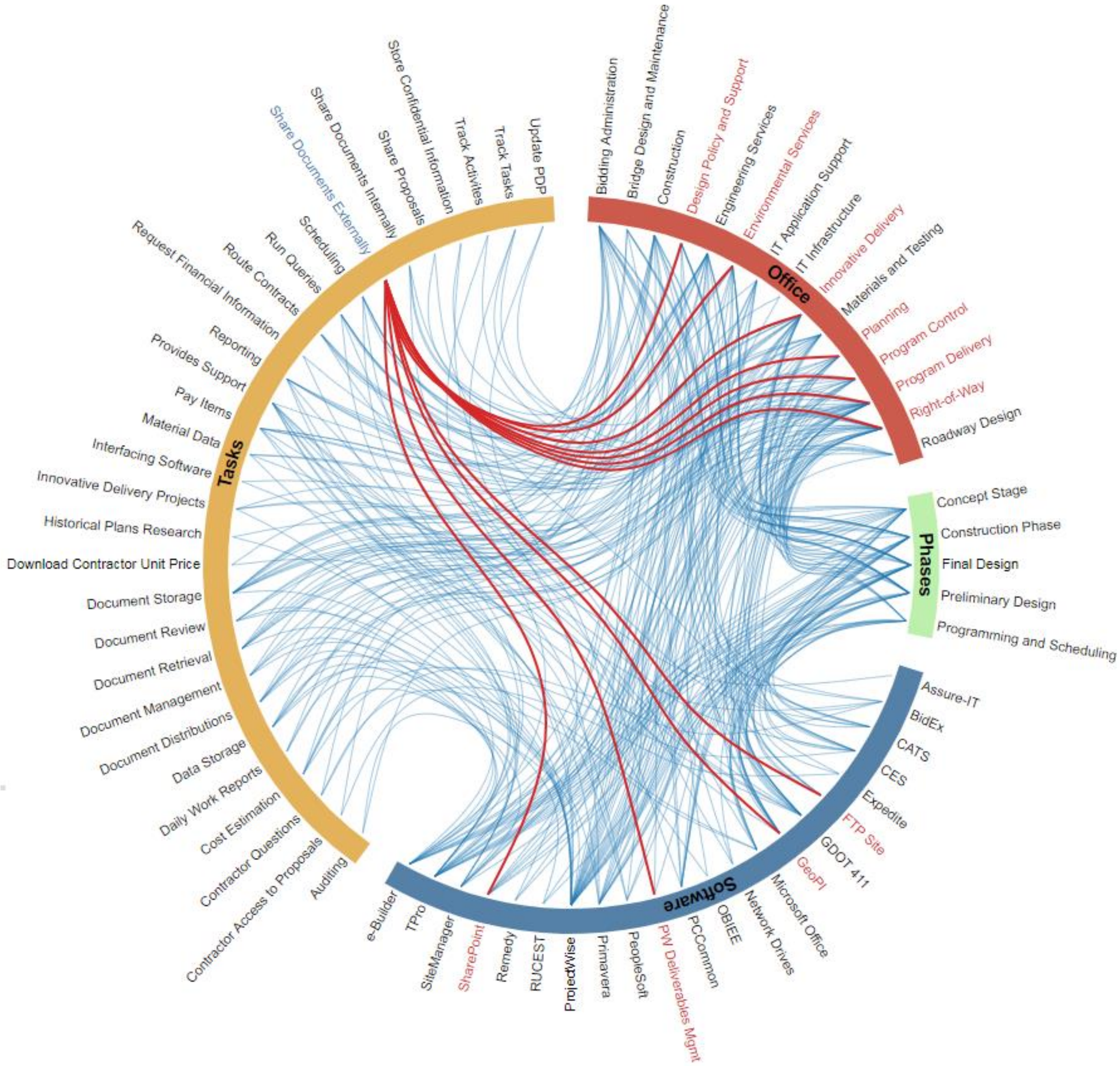


**Figure 30—Interactive Mapping Tool of GDOT Software Usage (External Document Sharing)**

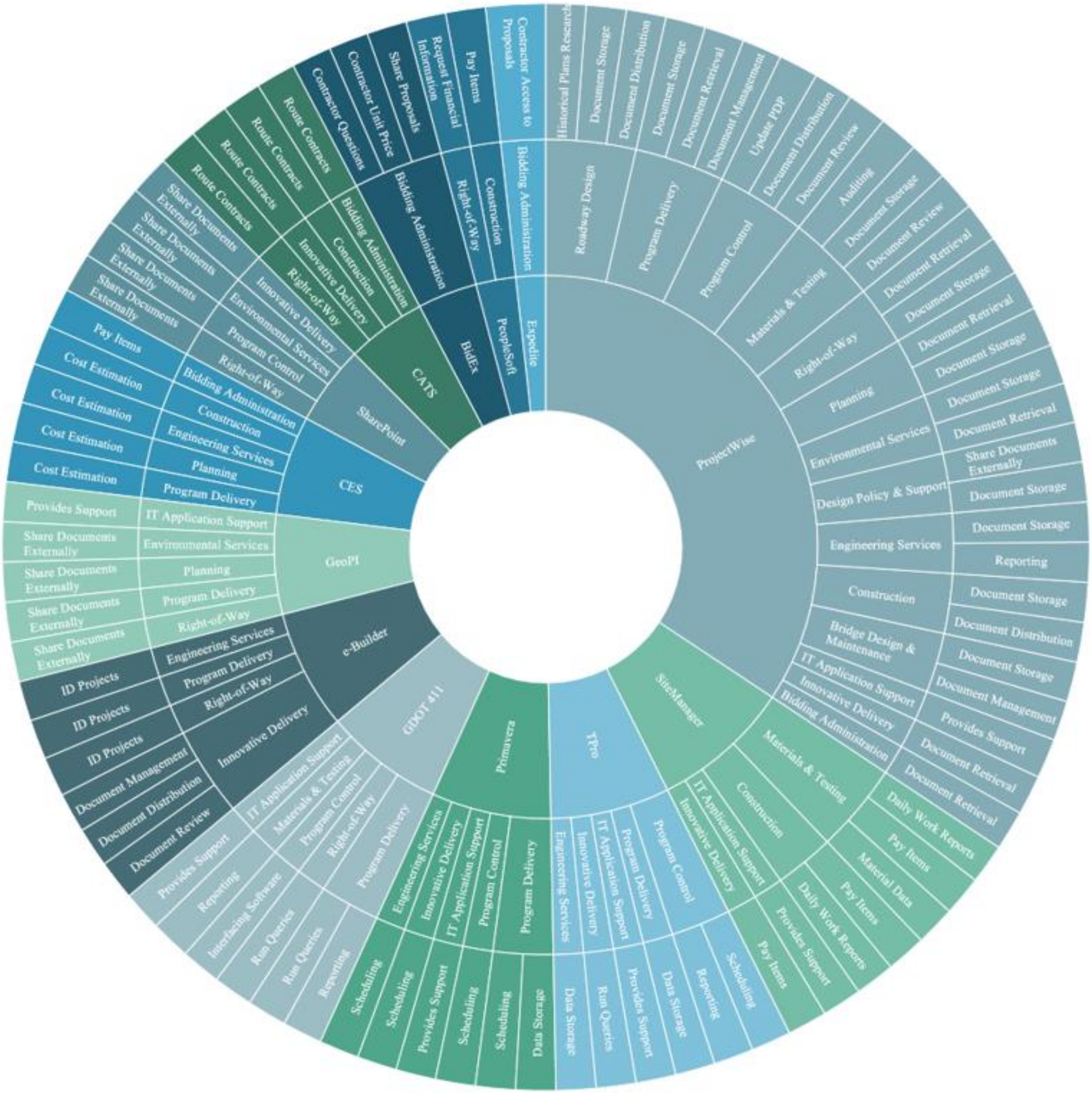


**Figure 31—Mapping Diagram of GDOT Software Usage**

The meetings with GDOT offices revealed common challenges regarding e-Construction processes, which are summarized in Table 15. Several offices mentioned the need for automating processes and creating workflows and creating a plan for where to store documents that do not have a project number. In addition, offices see a need for improved electronic document distribution and software training, specifically for ProjectWise. There is also an issue with having documents in several locations and too many software programs with overlapping capabilities. Additionally, some programs might need to modified to accommodate certain tasks and improve functionality. These challenges can later be used to assess the effectiveness of new e-Construction innovations.

**Table 15—GDOT E-Construction Challenges**

| Challenge | Frequency | Offices |
|---|---|---|
| Automating processes/workflows | 5 | Bidding Administration<br>Environmental Services<br>IT Application Support<br>Program Control<br>Right-of-Way |
| Documents without a PI number | 4 | Bidding Administration<br>Bridge Design<br>Environmental Services<br>Planning |
| Electronic document distribution | 4 | Bidding Administration<br>Engineering Services<br>OMAT<br>Program Control |
| ProjectWise training | 4 | Engineering Services<br>Environmental Services<br>Program Delivery<br>Right-of-Way |
| Real-time information exchange | 3 | Construction<br>Program Control<br>Roadway Design |
| External access to ProjectWise | 3 | Construction<br>Environmental Services<br>Program Delivery |

| | | |
|---|---|---|
| Converting old projects documents to electronic versions | 3 | Construction<br>ODPS<br>OMAT |
| Duplicate documents in various locations | 3 | Construction<br>IT Application Support<br>Right-of-Way |
| Unable to query in ProjectWise | 2 | Construction<br>IT Application Support |
| Too many software programs with overlapping capabilities | 2 | Environmental Services<br>Right-of-Way |
| Too many document sharing programs among external agencies | 2 | Environmental Services<br>IT Infrastructure |
| e-Builder | 2 | Environmental Services<br>Program Delivery |
| TPro modifications | 2 | Program Control<br>Program Delivery |
| Document size limitation in CATS | 1 | Bidding Administration |
| Interoperability of SiteManager and ProjectWise | 1 | Construction |
| Unable to respond to emails outside of the office | 1 | Construction |
| Clear milestones/timestamps | 1 | Construction |
| Availability to print plans | 1 | Engineering Services |
| Certain files cannot be created/opened in ProjectWise | 1 | Environmental Services |
| Too many folders in ProjectWise | 1 | IT Application Support |
| IT access to PeopleSoft | 1 | IT Application Support |
| Connectivity | 1 | IT Infrastructure |
| Keeping up with advances in technology | 1 | IT Infrastructure |
| Functionality of SiteManager | 1 | OMAT |
| Heavy reliance on IT | 1 | OMAT |
| Unnecessary automatic distribution | 1 | OMAT |
| Organization of requests | 1 | Program Control |

### 5.2.3 | FHWA AID Demonstration Project Narrative

Using the information collected from the meetings with GDOT offices, a draft Project Narrative was developed on GDOT's behalf. In the narrative, funding is requested for three major e-Construction initiatives: enterprise application integration, software training, and new technologies.

#### 5.2.3.1 | Project Abstract

Since December 2016, the Georgia Department of Transportation (GDOT) has been assessing the performance and process for carrying out e-Construction and preparing for full deployment of current e-Construction initiatives by December 2018. However, GDOT Research Project 17-13 "Development of Implementation Plan for GDOT e-Construction Program" was conducted in 2017-2018 and determined technical and organizational barriers within the department and among external agencies related to the agency's e-Construction program. All of GDOT's offices currently employ e-Construction processes to some degree, however, the department sees a need for improved communication and document sharing through enterprise application integration. Furthermore, GDOT would like to invest in additional training for recently employed software programs and assess new e-Construction technologies. This project is intended to improve GDOT's planning and construction processes by developing and deploying "new tools, techniques, and practices to accelerate the adoption of innovation in all aspects of highway transportation."

#### 5.2.3.2 | Project Description

The goal of this project is to implement more efficient e-Construction practices to be adopted by the state's transportation community and used regularly on all projects. GDOT currently utilizes several software programs to facilitate electronic processes throughout all phases of construction. ProjectWise Construction Management, which was purchased in 2013, is currently the most widely used program by the department. This software is mostly used for document distribution, review, and storage. GDOT utilizes AASHTOWare Project Cost Estimation System (CES) for cost estimation and AASHTOWare Project SiteManager for daily work reports, material data, and pay items during construction. BidX and Expedite are used to facilitate the bidding process electronically. In addition, the department employs a number of in-house software programs, including TPro for data storage and reporting, Primavera for project scheduling, GeoPI to share documents externally, CATS to route contracts, PeopleSoft for financial information, and GDOT 411 to run queries among software programs. Some offices use SharePoint to share documents with contractors and other external agencies as well. Since GDOT's design-build projects are procured, regulated, and managed differently than other projects, the Office of Innovative Delivery uses e-Builder to distribute, review, and store documents for these projects. Field Construction Supervision Staff have been provided with the necessary equipment and technology to allow for access to electronic data in the field.

GDOT currently employs a multitude of software programs, several of which have overlapping capabilities. The department is interested in improving interfaces and data integration among these programs for more efficient information management throughout all phases of construction. Rather than replacing current software programs with a new one, GDOT aims to identify to what degree these software systems are interoperable with each other. Integrating these systems will provide a real-time and automated platform for data and information exchange. Timing of data and information exchange are essential in facilitating and expediting project development. One of the greatest challenges is the nature of GDOT's Plan Development Process (PDP), which is not necessarily sequential. Often, related tasks are concurrent, which makes efficient information exchange key to the success of the project. Despite the capabilities of

GDOT’s current software programs, construction documents are still distributed through email and sometimes mailed as hard copies.

Automating processes and creating workflows are challenges GDOT would like to address with this project. There is currently a need for more efficient communication between software as well as more efficient document transfer among offices. Implementing enterprise application integration, using ProjectWise as the primary software application, will allow automated document sharing and simplified document storage. Improving GDOT’s software interfaces will increase efficiency of document transmittal, review, and approval as well as enhance workflow management among all involved parties. Additionally, GDOT is interested in developing a robust training program for its employees and consultants for its newer software programs. Several software programs within the department are not being used to their full advantage, particularly ProjectWise. Advanced software training will further improve the buy-in and implementation of GDOT’s e-Construction program.

GDOT aims to assess new e-Construction technologies, including e-Ticketing, e-Tagging, and 3D Engineered Modeling. E-Ticketing is the process of electronically tracking and recording of construction material information. It has been shown to increase safety, efficiency, and accountability of material inspections by the Iowa Department of Transportation and other pilot studies. GDOT’s Office of Materials (OMAT) is interested in e-Ticketing, but more research needs be conducted prior to implementation. OMAT is interested in implementing an electronic process for tagging concrete cylinders as well. This process, also known as e-Tagging, will timestamp each cylinder with a barcode to specify break times. Construction personnel will use a hand scanner to create the barcode, and lab personnel will then scan the code at the lab. GDOT’s Information Technology Office is currently researching software to support this process. Another opportunity for improving GDOT's e-Construction program is to further implement the use of 3D Engineered Models for roadway design. According to the Federal Highway Administration, the use of digital data reference packages is anticipated to yield construction savings of approximately 6% and a time savings of 30-40%. The benefits of 3D models have been proven by the Missouri DOT and Oregon DOT. GDOT expects this new process to reduce cost, eliminate risk, and increase trust in plans.

#### 5.2.3.3 | Innovation Performance

The performance goals for the deployment of this innovation reflect the goals of the Technology and Innovation Deployment Program (TIDP). Specifically, this study will lead to improved efficiency throughout the construction process, thereby resulting in a cost savings to GDOT through the elimination of document printing, transmitting, and storing with reduction in communication delays and transmittal time. These performance goals will be monitored, assessed, and documented throughout several projects in relation to similar completed projects. Additionally, the department will track overall usage of ProjectWise and user proficiency of the software before and after training.

A timeline for the project is as follows: 6 months for project planning phase regarding enterprise application integration (October 2018 – March 2019); 12 months for development of software application integration (April 2019 – March 2020); 6 months concurrently developing and implementing robust training program (April 2019 – September 2019); and 12 months concurrently new technological innovations' assessments (April 2019 – March 2020).

#### 5.2.3.4 | Applicant Information and Coordination

This application is being submitted on behalf of the GDOT Office of Construction along with the Office of Performance-Based Management and Research. The point of contact for this project is:

John Hancock, Office of Construction Administrator

Address: Georgia Department of Transportation
One Georgia Center
600 West Peachtree St NW, 11th Floor
Atlanta, GA 30308
Email: jhancock@dot.ga.gov
Phone: (404) 631-1971

The implementation of this project will require internal coordination with other GDOT offices as well as external coordination with consultants and contractors. The GDOT offices involved with this process include Bridge Design and Maintenance, Construction Bidding Administration, Design Policy and Support, Engineering Services, Environmental Services, Innovative Delivery, Materials and Testing, Planning, Program Control, Program Delivery, Right-of-Way, and Roadway Design. IT Application Support and IT Infrastructure will be involved with the development, operation, and management of computer hardware and software.

**5.2.3.5 | Funding Request**

The Georgia Department of Transportation requests the full $1 million of available funding to streamline its current e-Construction practices as well as facilitate the assessment of new e-Construction technologies. The research conducted under GDOT Research Project 17-13 critically examined the current state of utilization of different software systems and technologies related to e-Construction at GDOT and identified needs for advancing the department's e-Construction program. The requested AID Demonstration funding will promote enterprise application integration, software training, and the assessment of new innovations. A breakdown of the requested funding is attached.

**5.2.3.6 | Eligibility and Selection Criteria**

As a state department of transportation, GDOT is eligible to apply for funding. The Georgia Department of Transportation has not previously received any AID Demonstration funding. This project is eligible for assistance under Title 23 USC. GDOT is prepared to initiate the project within 6 months of applying for the funding.

The project demonstrates an innovation with a technology readiness level in the development phase as defined by Table 1 of the Notice of Funding Opportunity. GDOT considers the Basic Research and Applied Research phases to be completed by RP 17-13 and other state DOT results. e-Construction is an EDC-3 (2015-2016) innovation and directly applies to the highway transportation industry, benefiting aspects of planning, financing, operation, structures, materials, pavements, environment, and construction. E-Construction has been proven in-real world applications, and documented benefits have been provided by the FHWA and State DOTs. Although GDOT currently employs aspects of e-Construction, it has not implemented department-wide electronic document management.

GDOT accepts FHWA oversight of the project and will participate in monitoring and assessment activities regarding the effectiveness of the innovation. Additionally, GDOT will conduct a customer satisfaction survey before and after implementation of the innovation as standard practice. GDOT is committed to deploying this innovation as standard practice for the future of the department. GDOT will submit a report assessing the effectiveness of the project to the FHWA within 6 months of completion.

## 6.0 FUTURE WORK

### 6.1 | Bridge Load Rating

The research completed in this study demonstrated a proof of concept for a bridge load rating method using influence surface areas. The study generally analyzed two vehicle configurations on one bridge using one software program. Although ANSYS Workbench 18.2 was sufficient for this study, other software programs should be explored to determine which one best supports this method. In order to calculate an accurate load rating of the entire bridge, more than one bridge element should be analyzed. Future studies could determine how the load rating of a bridge changes when taking into account bridge substructure, for example.

In addition, further research should be conducted to determine how mesh refinement of influence surfaces affects the output and load rating results. In this study, the deterioration of bridge elements was accounted by post-processing the results. Another way to represent deterioration of the bridge is to change the material properties within the software prior to running the analysis. To further justify this load rating method, other studies should be conducted on different bridge types with different vehicle configurations.

### 6.2 | E-Construction

Presented in this study is an e-Construction implementation plan, based on the ideas of the representatives from the particular GDOT offices that were interviewed. The findings from this study can be used by GDOT to finalize a schedule for the planning, development, and implementation of more advanced e-Construction initiatives. A cost breakdown of the requested funding should be developed and included with the final AID Demonstration Project Narrative. In order to create an accurate estimate, the department should work with the Information Technology Office to determine what is required to implement enterprise application integration, software training, and new technologies.

GDOT and other transportation agencies should discover ways to integrate information among their most commonly used software programs for more efficient project administration. In addition, transportation agencies can greatly benefit from robust training programs and workflows for new document management software. Future studies should be conducted to explore new e-Construction technologies, such as e-Ticketing and e-Tagging. It is important to research the experiences of other state DOTs and conduct pilot studies before implementing new innovations department-wide. After any new e-Construction innovation is implemented, assessments should be conducted to determine how it has affected project efficiency.

## 7.0 CONCLUSIONS AND RECOMMENDATIONS

### 7.1 | Bridge Load Rating

The Sanford Drive Bridge in Athens, Georgia was used as a case study for a load rating method using influence surface areas in ANSYS Workbench 18.2. Unit loading was applied to the node locations of the worst load case on Span 7 of the bridge. Results for Equivalent (von-Mises) Stress and Maximum Shear Stress were recorded at several locations in the fourth beam of the span. These results were then added together to determine the total moment and shear demand for two different vehicle positions. The positions did not necessarily represent the vehicle being in different locations, but different nodes being used to demonstrate the same effect of one vehicle position. The moment and shear demand were then compared to the beam capacity to determine a load rating factor for several cases of deterioration.

As the results show, the load rating factor for the control and deterioration cases of both positions are very similar. The Equivalent Stress results yielded the greatest change in rating factor for a 1/2" section loss in the beam web, and the smallest change in rating factor for a 1/8" section loss in both beam flanges and the web. The Maximum Shear results did not have as much of an impact on the load factor rating. However, the greatest change in rating factor for both positions was for a 1/2" section loss in the beam web. For Position 1, the smallest change in rating factor was a 1/8" section loss in both flanges and a 1/4" section loss in the bottom flange. For Position 2, the smallest change in rating factor occurred with a 1/8" section loss in the bottom flange.

There are several benefits of the load rating approach outlined in this study. This method provides the ability to add the load effects from applicable nodes, depending on vehicle positions, after running the finite element model only once. Once the results have been collected, they can be manipulated to reflect any magnitude of traffic load or loading configuration. Furthermore, the results can be post-processed to account for existing section loss of bridge elements to update a structure's load rating, provided that the structure remains elastic.

In addition to revealing the benefits of this load rating approach, this study yielded recommendations for future use. It is important to include nodes on the bridge deck where the loads should be applied to avoid having to apply them to the nearest node. Additionally, it is recommended to include nodes where results are desired, whether it be in the beam flange, web, or other locations. In this case, it would have been beneficial to have nodes at the centerline of the web for the maximum shear stress measurements.

**7.2 | E-Construction**

The findings of this study revealed the limitations of GDOT's current e-Construction program by providing insight into the software usage and communication among its internal offices. In addition to in-house software programs, there are three different types of software being used at GDOT: Bentley Software, AASHTOWare, and e-Builder. The most widely used software program is Bentley ProjectWise, which is used for document distribution, retrieval, storage, and management. In some cases, it is used for Historical Plans Research, updating the PDP, sharing documents externally (with ProjectWise Deliverables Management), or reporting. AASHTOWare Project SiteManager is primarily used for daily work reports, pay items, and material data during construction. E-Builder is the software used by Innovative Delivery Office throughout the entire lifecycle of a project.

Overall, it is recommended that GDOT focuses on improving three aspects of its e-Construction program: enterprise application integration, software training, and new technologies. Rather than replacing several software programs with another new software, such as

AASHTOWare Project, improving communication among current applications is believed to be more beneficial and cost-effective. Enterprise application integration will help automate processes and workflows, which is the most common challenge among GDOT offices. Software training and new e-Construction technologies will have a lasting impact on the efficiency of the department's construction administration processes.

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**APPENDIX A: Mapping of Current GDOT Software Usage**

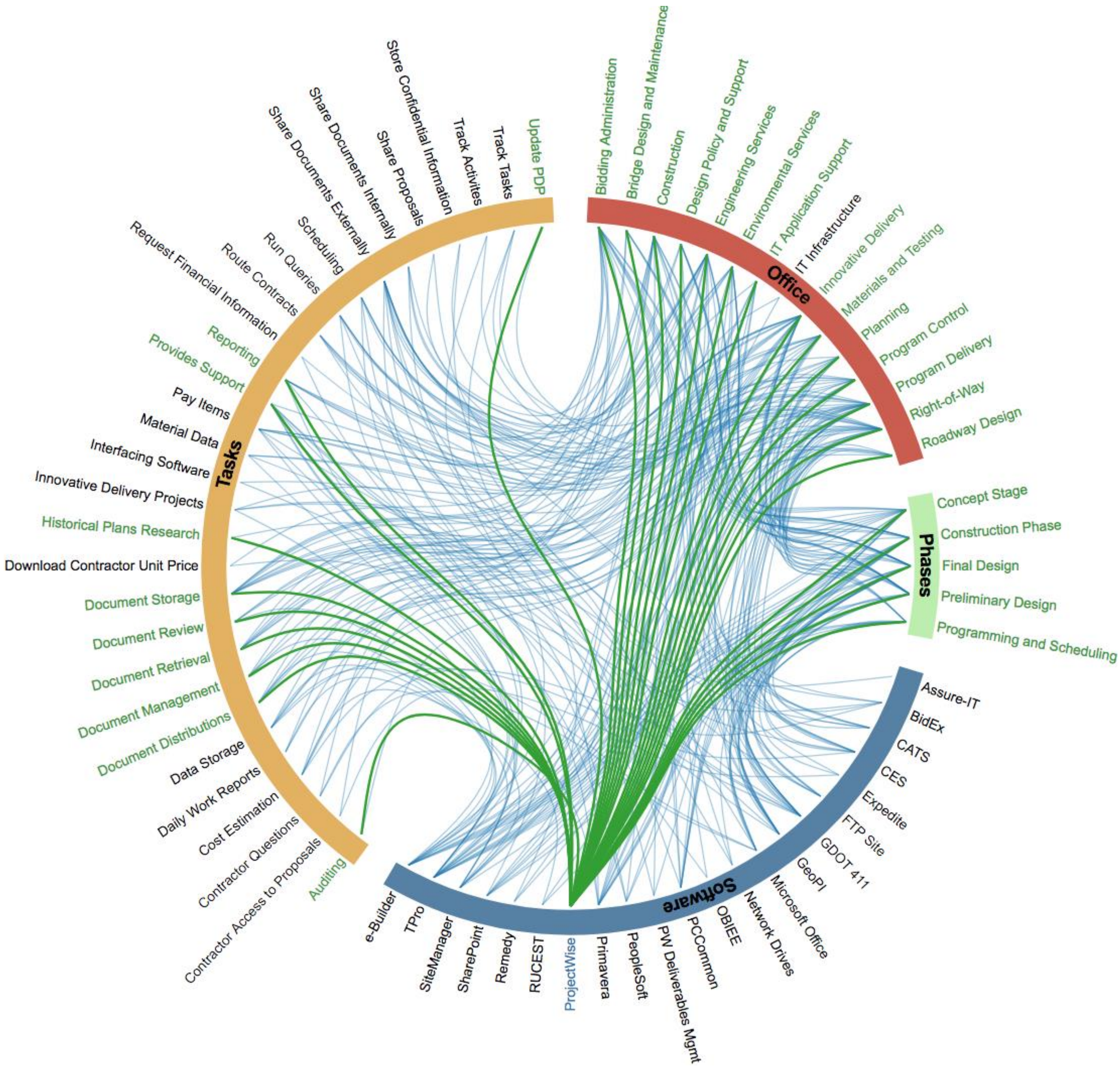


**Figure A1—Interactive Mapping Tool of GDOT Software Usage in Relation to Office, Project Phase, and Task**


Figure A2—Mapping Diagram of GDOT Software Usage in Relation to Office and Task