UNDERSTANDING CRITICAL IMPACTING FACTORS AND TRENDS ON BRIDGE DESIGN, CONSTRUCTION, AND MAINTENANCE FOR FUTURE PLANNING

Quarterly Progress Report
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Background and Introduction

Various impacting factors, such as technology advancement, climate change, economic shifts, and evolving behaviors and preferences of travelers have driven the changes in the infrastructure sector at an unprecedented speed. Bridges are an integral and important part of transportation infrastructure systems and are inevitably being affected by these factors (Baker et al. 2016). In this project, critical impacting factors are defined as the factors that may be considered unproven, lacking refinement, relatively unknown, but have the potential to affect bridge design, construction, and maintenance (DCM) in the short- or long-term.

Technology has long been the driving force to the advancements in the infrastructure sector, and the emerging technologies in vehicles, e-commerce, mobility services, and communications, etc., are expected to revolutionize the transportation industry and impact bridge DCM. For example, Connected and Automated Vehicle (CAV) technology allows for the platooning of heavy goods vehicle, which could significantly change the loading on long-span bridges and requires updating the load model in the design of bridge structures (CATAPULT 2017). A number of studies (e.g., CATAPULT 2017, Baker et al. 2016) have been conducted to understand how to integrate CAV technology into state departments of transportation's current bridge design and inspection workflow.

Similar to other transportation infrastructures, bridges are vulnerable to a range of threats from climate change, such as sea level rise, increasingly intense hurricanes and precipitation, and more frequent flooding. Research shows that economic losses due to climate change factors will increase by at least 15% and the expected number of annual bridge failures due to climate change will increase by at least 10% (Khelifa et al. 2013). Climate change will result in a significant increase in the level of structural vulnerability and material vulnerability in bridges (Khelifa et al. 2013). Flooding risks in particular will significantly affect bridge design; many researchers (e.g., Bhatkoti et al. 2016) have thus been calling for the re-evaluation of flood risks of existing bridges and the establishment of new design standards for future bridges.

Economic activities and demographic characteristics of the local community can also have great impact on the bridge DCM. For example, as exogenous drives of transportation demand, employment rate and personal income (Brownstone and Golob 2009) not only determine the overall volume of vehicles, but also the types of vehicles travelling on bridges, both of which are important factors to consider when modelling traffic loads during bridge design and maintenance.

Social demographics can affect bridge DCM in several different ways. On one hand, social demographic trends, such as slow population growth, aging population, more diverse workforce, can directly impact the traffic volumes on bridges. On the other hand, the "next generation" of communities may bring new cultural demand for bridges to go beyond a means for traffic to cross over barriers. For example, the 11th Street Bridge Park in Washington, D.C. is a place that connects people and generates inspirations for local communities (Bennett 2015).

Problem Statement

These technological, environmental, economic and social factors are occurring and evolving at an ever-increasing pace, and there is a growing awareness that these changes will reshape bridge DCM over the next decades. However, how these changes will affect bridge DCM in both the near- and long-term are not entirely clear, due to two challenges. First, it is difficult to predict the trends of these factors – whether it is a long-term lasting force, a temporary phenomenon, or it changes course as situation alters. Second, it is challenging to understand the interplay between these factors and bridge DCM. Multiple factors could interplay with each other to pose new uncertainties and/or requirements for bridge DCM. For example, travel behaviors are affected by advanced technologies, which is regulated by policies and regulations, all of which could impact bridge DCM. It is often multiple factors that drive the demand and changes on bridges.

Transportation planning agencies are responsible for making investments on bridges that often have long lasting effects to the traveling public and the society as a whole. A holistic and deep understanding of critical impacting factors and their trends, as well as the potential interactions among the factors and bridge DCM, will allow the agencies to become more proactive to changes rather than reactive. The ability to account for the impacts of critical impacting factors will also benefit post-deployment studies that evaluate the effectiveness of asset management and operation strategies. Accordingly, the decision makers and policy makers can develop long range bridge DCM plans, and recommend bridge investment and policies in a wise and adaptive manner. The project will also facilitate the practices of bridge DCM in a way that is sustainable, resilient, and offers lasting value to the communities.

Objectives and Research Approach

The main objective of this project is to understand the trends of critical impacting factors and examine how these factors may impact the way that bridges are designed, constructed, and maintained. The project also intends to provide a summary of the research results in a concise form for decision makers to consider in their bridge DCM.

The study will employ a combination of theoretical and empirical studies. It will start by exploring secondary sources of information from published literature, reports and policies that pertain to all potential factors that affect bridge DCM. After a thorough study of existing literature, an analysis will be conducted to ensure that a comprehensive list of factors have been identified and classified for proper documentation. A consolidated list of critical impacting factors will then be constructed through surveys and interviews with stakeholders (e.g., FDOT engineers, contractors, academic experts) of bridge DCM. A panel of experts will then evaluate and discuss the findings of this study during the 2019 International Accelerated Bridge Construction Conference in December 2019. This expert panel will further polish the findings by amalgamating opinions from academia, industry practitioners and public agencies together. The final report will reflect the true image of critical impacting factors in bridge DCM and will help all stakeholders involved in bridge DCM in making future decisions.

Description of Research Project Tasks

The following is a description of tasks carried out to date.

4 Task 1 – Identification of potential impacting factors.

Proposed task description*:* This task aims to identify all potential impacting factors on bridge DCM through a comprehensive literature review. Literatures will be (1) from multiple sources such as academic journals, white papers, reports, and policy documents from different agencies (e.g., DOT, TRB), and (2) in different domains, such as bridge DCM, technology advancement, climate change, etc. The identified impacting factors will include but are not limited to technological, environmental, social, and economic factors that influence bridge DCM. This task will generate an encyclopedia of all the identified impacting factors and classify them for proper documentation.

Description of work performed up to this period: We have conducted a comprehensive literature review that focuses on multiple domains, including bridge DCM, ABC, technology advancement in infrastructure, climate change and its impact on infrastructure, social and economic impact on infrastructure, and etc. The literatures are from multiple sources such as academic journals, white papers, reports, and policy documents from different agencies (e.g., DOT, TRB). A total of 26 impacting factors have been identified based on the literature review. The factors are classified into four main categories: environmental, social, economic, and technological factors. The deliverable of this task is a table that summarizes a preliminary list of identified factors. We have included the table as **Appendix A**.

5 Task 2 – Understanding the trends of impacting factors

Proposed task description: This task aims to understand the future trends of each of the identified impacting factors from Task 1 using secondary source materials. The indicators of the trend of each impacting factor will be identified. For example, total miles driven by CAVs can be used as an indicator of the trend of CAVs. The data of each indicator will then be collected. The data source may include but is not limited to Bureau of Economic Analysis, Bureau of Census, Bureau of Labor Statistics, Federal Reserve Board, Department of Commerce, Department of Revenue, and Enterprise Florida, etc. The data will be well-regarded, regularly generated and accessible through public sources with low cost or free. The main outcome of this task will be understanding the future trends of each of the identified impacting factors, how they may evolve over the course of next three to five decades, and how their future trends will influence bridge DCM.

Description of work performed up to this period: We first identified indicators of the trend of each impacting factor through a comprehensive literature review (e.g., Vose et al. 2005; Gaffen and Ross 1998; Pryor et al. 2009). We followed the following principles when selecting the indicators: (1) reliability and scientific soundness, (2) relevance to project context, (3) data availability, and (4) understandability and easiness of interpretation. The indicators are summarized in **Appendix C**. We then collected data for each of these indicators to understand the trend of the impacting factors. The data sources include the ones described in the proposed task description and other agencies such as National Oceanic and Atmospheric Administration, United States Environmental Protection Agency, National Center for Education Statistics, and etc. We classified the trends into four main categories: increasing, decreasing, varying, and unpredictable. For example, according to the data in recent years, the possibility of extreme maximum temperature (an environmental impacting factor) is increasing; while the unemployment rate (a social impacting factor) is decreasing. These trends will inform us how the factors might impact the Bridge DCM in the coming future. The trends for each of these indicators are summarized in Appendix C. The trends were further evaluated through a survey with domain experts as described in Task 3.

6 Task 3 – Identification and analysis of critical impacting factors

Proposed task description: This task aims to identify the critical impacting factors on bridge DCM through empirical studies. Stakeholder surveys and interviews will be conducted with bridge DCM stakeholders (e.g., FDOT engineers, contractors, academic experts). A questionnaire survey will be designed and implemented. The questionnaire will include two main sections: (1) background information of the respondents; (2) impact assessment of the identified factors. The identified impacting factors will be presented to the respondents, who will then rate the potential impact and probability of occurrence using five-point Likert scales, with 5 being “very high impact” and “very high probability” and 1 being “very low impact” and “very low probability”; and (3) open-ended questions that ask respondents to further elaborate on how each trend could impact bridge DCM.

At the end of the questionnaire, the participants will also be asked about their willingness to participate in a post survey interview. The survey will be implemented online using Qualtrics. Based on the survey results, statistical analysis (e.g., mean indexing, Kruskal-Wallis H test, factor analysis) will be conducted to identify a list of critical impacting factors.

Description of work performed up to this period:

Expert Interview. We first used a qualitative approach to understand experts' perspectives on the factors that could affect bridge DCM in the future. The primary data collection method was in-depth semi-structure interviews with experts in bridge engineering domain. A set of open-ended questions were grouped into three major sections: (1) bridge design, (2) bridge construction, and (3) bridge maintenance. Under each of these sections, a similar set of open-ended questions were asked. Examples of questions include: Based on your expertise in Bridge Engineering, what are the critical factors that could affect the design standards of our future bridges? Can you explain why you believe the factors could affect the design standards of future bridges? Can you explain how these factors could affect the design standards of future bridges? The interview instrument is included as **Appendix B**.

We have contacted for more than 70 domain experts for expert interviews. The experts include state DOT bridge engineers, construction superintendents, transportation engineers, university professors, and etc. The invitations were sent out through emails. The interviews aim to solicit experts' opinions on the importance, trends, and impacting mechanisms of critical impacting factors. The interviews were conducted between Dec 2019 and Feb 2020. We have collected a total of 20 responses. The interviews were audio recorded.

Prior to coding of data, the recorded interviews were automatically transcribed using Sonix (SONIX 2020) and were checked for accuracy and revised manually. Data collected from the interviews (including the transcription data) was imported into NVivo (QSR International 2020), a qualitative analysis software. We then analyzed the data to extract and identify the critical impacting factors. Besides the factors already identified through literature review (in Task 1), we identified additional 14 factors. These new factors and their trend analysis are both included in **Appendix C**.

Expert survey. Besides the interview, we also conducted an expert survey to further gather quantitative responses from bridge domain experts. We designed a questionnaire survey, which includes three main sections: (1) Impact assessment of the identified factors. The identified impacting factors were presented to the respondents, who can then rate the potential impact and probability of occurrence using a five-point Likert scale, starting with "extremely likely" followed by "very likely", "likely", "not likely" and "no impact"; (2) trend analysis of the factors using a four-point Likert scale with options including "trend continues", "trend stops", "trend reverses" and "unpredictable trend"; and (3) background information of the respondents and open-ended questions that ask respondents to provide any additional impacting factors or trends that were not covered in the questionnaire. The participants were also asked about their willingness to participate in a post-survey interview.

A pilot study was first conducted to test the effectiveness of the questionnaire. Five respondents participated in the pilot study. They were requested to complete the survey as a bridge expert, and to provide feedback on the format, content, and length of the survey. Feedback was solicited on different aspects of the survey, such as instructions to the respondents, question wording, clarity of factors, evaluation scales, and visual appearance. The questionnaire was then revised based on the feedback. For example, more examples were added to each of the trends to improve the clarity of trend analysis. Some background questions were reworded to avoid potential confusions to respondents. The visual appearance was edited to ensure the consistency of fonts that were used. The final version of the questionnaire survey is included in **Appendix D**.

The survey was implemented on Qualtrics from Apr 2020 to Jul 2020. A survey invitation and a link to the questionnaire were sent out through email. The survey targeted bridge experts and stakeholders in the government agencies (e.g., DOTs, AASHTO), academia, and industry in the U.S. Potential respondents were sampled from different open online sources, such as government websites, online address books, and etc. Up until Aug 31, 2020, we have sent out around 600 invitations to individual email accounts. We have also sent out the survey through an email list that includes around 1,000 bridge stakeholders. A total of 115 participants have responded to the survey, and 93 of them have completed the survey. The response rate is about 7%, and the completion rate is approximately 80%. It is worth noticing that COVID-19 has negatively affect the response rate as the normal survey response rate is around 20%-30% in the engineering sector (Akintoye 2020). Table 1 summarizes the demographic information of the participants.

The initial analysis of the survey results aimed at addressing the following research questions:

(1) What are the rankings of the critical impacting factors based on their likelihood of impacts on bridges in the future?
(2) What are the future trends of the critical impacting factors based on the experts' opinions?
(3) What are the rankings of the four main categories of factors (i.e., environmental factors versus social factors versus economic factors versus technological factors) based on their likelihood of impacts on bridges in the future?
(4) What are the factors that are most impactful and most likely to happen?

The following paragraphs present the preliminary survey results. Detailed discussions and analysis will be included in the final report.

(1) Ranking of critical impacting factors based on impacts. To determine the ranking of the critical impacting factors based on their likelihood of impacts on bridges in the future, the mean indexing method was first used to determine the *average impacting values* for each factor. To do that, numerical values of 5 to 1 were assigned to the responses ranging from "extremely likely" to "no impact". The critical impacting factors were then ranked based on the *average impacting values.* The results are summarized in Table 2. As per Table 2, the top five ranked factors include availability of funding, change in construction cost, change in intensity and frequency of extreme events, adoption of new construction materials or structures, and adoption of new construction techniques.
(2) Future trends of critical impacting factors. Similarly, mean indexing was used to determine the *average trending values* of each factor. To do that, numerical values of 3, 2, and 1 were assigned to "trend continues", "trend stops", and "trend reverses". Because of the uncertain interpretations of "trend uncertain", a numerical value of 0 was assigned to it to eliminate its impact on the results. The critical impacting factors were then ranked based on the *average tending values*. The results are summarized in Table 2. As per Table 2, the factors that are most likely to continue include adoption of new construction materials or structures, adoption of new construction techniques, and change in ways of management and communication; while the factors that are most likely to reverse include change in fuel price, change in taxation, and availability of funding.

Table 1. Demographic information of survey participants.

Demographic Parameters	No. of Participants
Total number of participants	93
Gender	
Male	82
Female	11
Age	
26-40	15
41-55	45
56-65	26
Above 65	7
Education	
High school graduate- high school diploma or the equivalent (for example: GED)	1
Some college credit, no degree	1
Bachelor's degree	40
Graduate degree	46
Doctoral degree (e.g., PhD, Research doctorate)	1
Professional degree (e.g., MD, JD)	3
Other	1
Employment Type	
Private-for-profit company, business or individual, for wages, salary or commissions	9
Not-for-profit, tax-exempt, or charitable organization	1
State government employee	66
Federal government employee	11
Self-employed	1
University	3
Other	2
Job Position	
University Faculty	3
Structural Engineer	25
Construction Engineer	43
Project Manager	13
Transportation Engineer	3
Maintenance Engineer	5
Hydraulic Engineer	1
Work Experience	
Less than 5 years	6
5 to 10 years	11
10 to 20 years	15
20 to 30 years	29
More than 30 years	32
Race	
Asian	8
White	78
Black or African American	2
American Indian or Alaska Native	1
Do not know	2
Other	2
Regions of U.S.	
Northeast (Connecticut, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island)	10
Midwest (Illinois, Indiana, Michigan, Ohio, Iowa, Minnesota, Missouri, Nebraska, North Dakota)	23
South (Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Oklahoma, Texas, Virginia, West Virginia)	37
West (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington)	22
I do not reside in the United States	1

(3) Ranking of four categories based on impacts. To compare the ranking of the factors on an aggregate level, the mean value of each of the four main categories of factors (environmental, social, economic, technological) was calculated by averaging the mean impacting values of the factors under each category. The results are summarized in Figure 1. As per Figure 1, the mean values of technological factors are higher than those of economic, social, and environmental factors.

(4) Most impactful and most trending factors. To support more effective and efficient decision-making for the future of bridges, there is a need to identify the most impactful and most trending factors based on the experts' opinions. These factors will be given higher priority for future planning purposes. In order to identify these factors, an impact-trend index is defined as

$$\text{Impact-trend index} = \text{average impacting value} \times \text{average trending value}$$

The results of impact-trend index for each factor are summarized in Table 2. Among all the factors, the most impactful and trending factors include adoption of new construction materials or structures, adoption of new construction techniques, change in construction cost, advancement in structural health monitoring techniques, and change in ways of management and communication. Among the five top ranked factors, four of them belong to technological factors.

The above paragraphs presented a summary of the preliminary analysis of the results. We will further analyze the results with more discussions. A complete analysis of the survey results will be included in the final report.

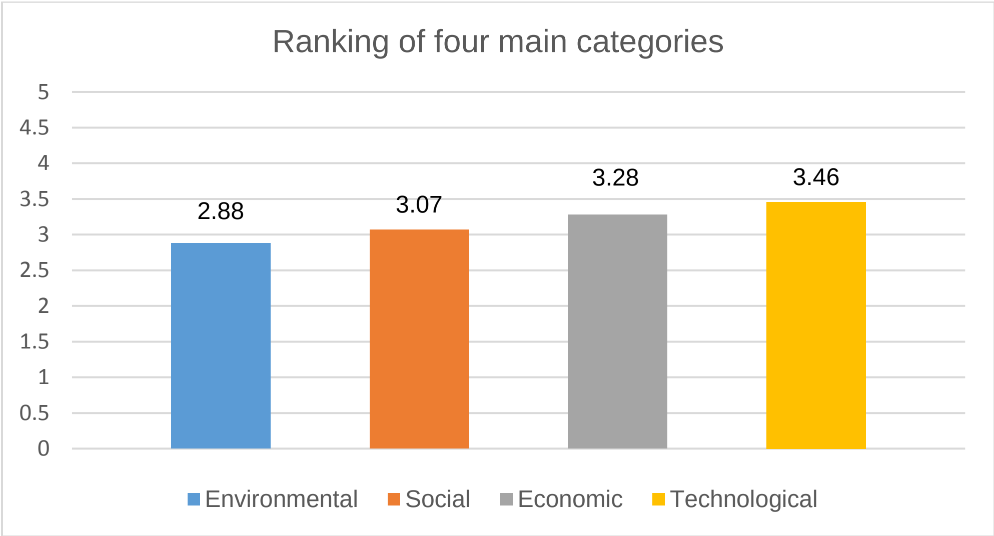


Figure 1. Mean impactful scores of the four main categories of factors

Table 2. Summary of Results.

Factor	Impact		Trend		Impact and Trend	
	Mean	Rank	Mean	Rank	Mean	Rank
Environmental						
Change in temperature	2.90	22	2.31	13	6.71	16
Change in relative humidity	2.44	28	1.77	21	4.33	26
Change in precipitation	3.37	8	1.88	19	6.33	18
Sea level rise	3.27	14	2.33	12	7.63	10
Change in intensity and frequency of extreme events	3.76	3	2.24	15	8.42	7
Change in air quality	2.28	29	2.09	16	4.76	22
Change in soil quality	2.44	28	1.67	23	4.07	27
Change in water quality	2.55	27	1.78	20	4.55	24
Social						
Change in demographic features	3.22	17	2.46	9	7.92	9
Change in socioeconomic status	2.61	25	1.69	22	4.41	25
Change in aesthetic preferences	2.62	24	1.52	26	3.98	28
Change in land use patterns	3.24	15	2.33	12	7.55	11
Change in legislation and policies	3.40	7	2.01	17	6.83	15
Change in risk tolerance	3.09	19	2.25	14	6.94	14
Change in labor market	3.32	11	2.00	18	6.65	17
Change in perceptions on careers	2.83	23	1.63	24	4.62	23
Education on new technical knowledge	3.34	10	2.52	7	8.41	8
Economic						
Economic growth	3.24	15	1.60	25	5.19	21
Change in fuel price	3.01	20	1.02	30	3.08	31
E-commerce growth	3.00	21	2.37	11	7.10	13
Change in road pricing	3.10	18	2.38	10	7.36	12
Globalization and trade war	2.59	26	1.43	27	3.71	29
Availability of funding	4.20	1	1.42	28	5.97	19
Public-private partnership trend	3.23	16	1.78	20	5.76	20
Change in construction cost	3.83	2	2.56	6	9.80	3
Change in taxation	3.31	12	1.10	29	3.63	30
Technological						
New transportation facilities or methods	3.30	13	2.58	5	8.52	6
Interference between human and traffic	3.35	9	2.51	8	8.41	8
Adoption of new construction materials or structures	3.68	4	2.81	1	10.32	1
Adoption of new construction techniques	3.66	5	2.74	2	10.02	2
Advancement in structural health monitoring techniques	3.42	6	2.71	4	9.27	4
Change in ways of management and communication	3.35	9	2.72	3	9.13	5

Description of work performed up to this period: N/A

7 Task 4 – Recommendations

Proposed task description: This task aims to develop a comprehensive list of recommendations for the transportation decision makers and policy makers to consider in their short- and long-term planning of bridge projects. These recommendations are based on consolidating the investigation and analysis of critical impacting factors from (1) literature review, and (2) expert surveys and interviews.

Description of work performed up to this period: Based on the results of the interviews and literature review, some possible actions for adapting to the top-ranked technological, environmental, social, and economic factors are recommended as follows:

(1) Technological Factors

The following strategies for adapting to the technological factors are recommended: First, adoption of new construction materials with increased life expectance and fewer maintenance needs is critical for the future of bridge infrastructure. However, the high initial costs could become a primary barrier for adoption. A "top down" approach, which requires the higher administrative-level policymakers to support industry research on new material or technique adoption, was recommended by a few experts. In addition, more research on the life-cycle cost analyses for new materials is recommended as they would offer new knowledge and evidence for demonstrating the long-term economic effectiveness of using new materials. These analyses can also be integrated into current material purchase standards to facilitate "best value" purchase. Second, the interviewees and researchers have been calling for the need of changing existing bridge design standards to accommodate and accelerate the deployment of new transportation facilities or travel methods (e.g., CAVs, hyperloops), which may require fundamental research on how these new methods could potentially affect the traffic loads, including both passenger travel and freight delivery. New load models may be integrated into the design of future bridge structures or the retrofit of existing ones. Third, for integration of any new technologies (e.g., structural health monitoring techniques, new communication or navigation tools) into the bridge sector, there is a need for multi-sector stakeholder collaboration that engages government agencies, private industries, and multi-disciplinary researchers to comprehensively facilitate the development and deployment of new technologies from both technical and policy-making perspectives.

(2) Environmental Factors

The following strategies to reduce the probability and/or consequences associated with environmental impacts on bridges are recommended: First, the existing design standards or building codes need to be constantly re-evaluated and updated to adapt bridge design and construction to the changing climate and rising sea levels. For example, the design rainfalls or design floods need to be re-evaluated on an annual basis and uncertainty parameters can be introduced for design criteria (e.g., design wave forces) that are largely impacted by the changing environmental factors. Second, use of new materials (e.g., UHPC, HPS) or construction techniques (e.g., accelerated bridge construction) are recommended by the experts as they could either allow the structures to be more durable and resistant to environmental impacts or reduce the impacts of bridge construction on the environments. Third, for the existing bridges, retrofitting strategies such as using corrosion inhibitors, cathodic protection, increasing concrete thickness, or using protective surface coating and barriers (Nasr et al. 2020, Stewart et al. 2012) could potentially control the increased corrosion rates caused by several environmental factors (e.g., climate change, sea level rise). Other strategies, such as the use of anchorage bars, concrete shear tabs, and increasing continuity, can be adopted for adapting to increased scour rates (Mondoro et al. 2018). Fourth, considering the availability of multiple adaptation strategies, cost-benefit analyses, or life-cycle cost analyses are needed to better understand which strategy to implement and when to implement it (Nasr et al. 2020).

(3) Economic Factors

The following strategies for adapting to the economic factors are recommended: First, when considering P3 for potential projects, governments may want to account for the benefits and costs through the project's entire life cycle. In addition, government agencies can take more efforts to standardize the P3 project assessment and development process, including how to determine if P3 is appropriate for a project, how to develop a comprehensive request for proposals for P3 projects, and how to decide which proposal to accept. Second, to cope with the budget shortfalls due to the reduced sales and gas tax revenue, state and local transportation agencies may need to reevaluate their typical project planning and programming policies to better align funding with decision making, achieve the best and highest use of infrastructure assets and revenues, and provide cost-effective solutions to current and future transportation needs. One potential solution is through right-sizing transportation infrastructure, which involves reassessing the size, extend, or composition of transportation infrastructure to reflect the current economic reality, such as relaxing or waiving standards, replacing infrastructure with more economical options, or decommissioning infrastructure to allow for land reuse (Duncan 2020). Third, to provide much-needed investment on critical bridge infrastructure and stimulate the economy, state and local governments are encouraged to leverage private capital through adopting P3, asset recycling, evaluating underutilized bridges or renegotiating lease arrangements. State and local governments are also recommended to integrate greater economic considerations into their project planning and evaluation process and prioritize bridge projects that support the local economy, enable job creation or retention, improve connectivity, amenity or other factors that lead to increases in local tax revenues (Falk et al. 2020).

(4) Social Factors

Societal preferences can change over time and since bridges and other infrastructure are built to outlive ever-emerging societal changes, meticulous study of societal factors is critical for bridge design, construction and operation. The following recommended strategies are offered: First, uplifting the technical skill level and preserving the dignity of the existing construction workforce while enticing the best minds of future generations to pursue a career in construction are essential to avoid the current labor shortage in construction. In addition, introducing new technologies, such as robotic and artificial intelligence, into the construction field could partially address the shortage of labor for certain construction activities, especially those that require repetitive works. Second, safety of human workers during construction and maintenance of bridges and safety of the community throughout the life cycles of bridges should be prioritized in all bridge projects. Construction work zones have long been associated with disruptions to regular activities, road closures, dust, and noise. While the construction workforce is exposed to all these nuisances and hazards, commuters and people living in the surrounding communities are also impacted depending upon their contact with the construction work zones. New real-time monitoring and preventive technologies can radically enhance the safety of construction work zones; deployment of modern technologies to track construction resources and activities can assist in avoiding hazards, regulating road closures and warning people on what to expect. New bridge construction techniques, such as Accelerated Bridge Construction can potentially improve the safety of construction processes because of reduction in hazard exposure time and area, and it also improves the overall societal perceptions on bridge construction as it facilitates minimal disruption of regular activities. With the development of new techniques and technologies, risk tolerance of the society is ever narrowing. Bridges are eventually constructed for societal good; safety of communities must be embodied into the bridge construction works and activities that it becomes a part of the community and culture.

We will include further recommendations based on the results from the expert survey.

8 Task 5 – Final report

Proposed task description: A final report summarizing the entire project activities will be prepared and will be submitted at the project conclusion. The final project deliverables will include production of audio-visual products that could be used to easily convey the project findings with stakeholders.

Description of work performed up to this period: N/A

Expected Results and Specific Deliverables

Table 3 summarizes the main deliverables of each task.

Table 3. Project tasks and deliverables

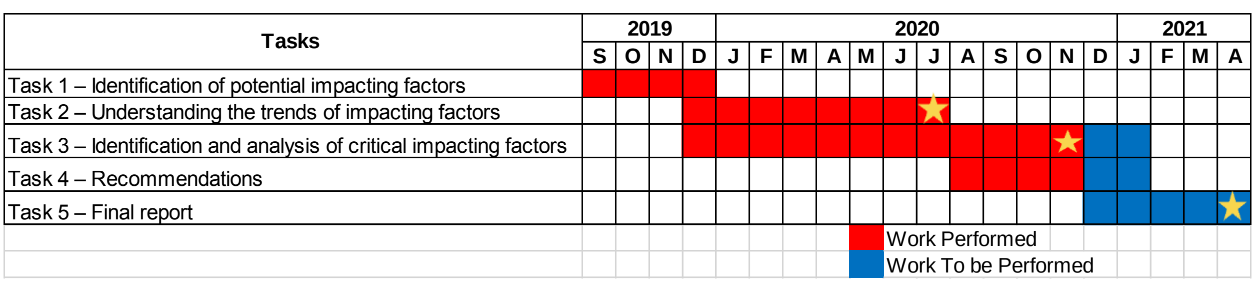
Task	Deliverable
Task 1 – Identification of potential impacting factors	A list of all potential impacting factors
Task 2 – Understanding the trends of impacting factors	Analysis of trends of impacting factors
Task 3 – Identification and analysis of critical impacting factors	A list of critical impacting factors from stakeholders' perspectives
Task 4 – Recommendations	A set of recommendations
Task 5 – Final report	Final report, audio-visual products that present research findings

Schedule

The progress of the tasks in this project is shown in Table 4 and Figure 2 below.

Table 4. Project timeline (percentage of completion)

Item	85% Completed
Task 1 – Identification of potential impacting factors	100%
Task 2 – Understanding the trends of impacting factors	100%
Task 3 – Identification and analysis of critical impacting factors	80%
Task 4 – Recommendations	70%
Task 5 – Final report	30%



Note: The stars denote the critical milestones of the project

Figure 2. Project timeline

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Appendix A

#	Factor	References
		Environmental Factor
1	**Change in temperature**	Rowan et al. (2013); Meyer (2008); Savonis et al. (2008); Hegemen (2019); Peterson et al. (2008); Grant (2018), NOAA (2020)
1.1	Change in extreme maximum temperature	Rowan et al. (2013); Meyer (2008); Ballesteros-Perez et al. (2015); CEI (2020)
1.2	Change in range of max and min temperatures	Rowan et al. (2013); Meyer (2008); Zhu et al. (2013); Regmi and Hanaoka (2011; Vose et al. (2004, NOAA (2020)
2	**Change in relative humidity**	Rowan et al. (2013); Nasr et al.(2019); IPCC (2013); Gaffen and Ross (1998)
3	**Change in precipitation**	Rowan et al. (2013); Regmi and Hanaoka (2011); Mondoro et al. (2017); Grant (2018); IPCC (2013); Nasr et al. (2019); NOAA (2020)
3.1	Change in overall precipitation	Rowan et al. (2013); Meyer (2008, Ballesteros-Perez et al. (2015); NOAA (2020);
3.2	Increased intense precipitation	Rowan et al. (2013); Meyer (2008); Nasr et al. (2019); globalchange (2020
4	**Sea level rise**	Rowan et al. (2013); Meyer (2008);Jaroszweski et al. (2010); Peterson et al. (2008), Nasr et al. (2019); Mondoro et al. (2017); NOAA (2020
5	**Change in intensity and frequency of extreme events (e.g., hurricanes, flooding, earthquakes)**	Rowan et al. (2013); Mondoro et al. (2017);Meyer (2008); Kirshen et al. (2002); Leonard et al. (2014); IPCC (2013); Nasr et al. (2019); NOAA (2020); Torn and Snyder (2012); Landsea and Franklin (2012)
5.1	Stronger wind loads	Rowan et al. (2013); Modoro et al. (2017); Ballesteros-Perez et al. (2015); Meyer (2008); Sara C Pryor et al (2009)
5.2	Greater storm surges	Rowan et al. (2013); Meyer (2008); Kirshen et al. (2002); R.A. Flather (2001)
5.3	**More frequent earthquakes**	Panakkat and Adeli 2008;
6	**Change in air quality**	Bastidas-Arteaga et al.(2013); Stewart et al. (2012); IPCC (2013); CDC (2020, J. Jcaob (2008, EPA (2020
6.1	Increased GHG and CO2 emission	Bastidas-Arteaga et al.(2013); Nasr et al. (2019); Stewart et al. (2012); IPCC (2013); Wang et al. (2010); globalchange (2020); OECD (2020
6.2	Atmospheric pollutants (e.g., sulphates, chlorides)	Kumar and Imam (2013); Nasr et al. (2019); Wang et al. (2010); EPA (2020, Thomas et al. (2000);
7	**Change in soil quality (e.g., soil salinity)**	Dasgupta et al. (2015); Gil-Sotres et al. (2004); Soilquality (2020)
8	**Change in water quality**	Nasr et al. (2019); Larsen (2018); Emongor (2005); ICRA (2020); Walker and Fitzsimmons (2019);
		Social Factor
1	**Change in demographic features**	Gardoni and Murphy (2018); Unicef (2020)
1.1	Change in population growth rate	Colebatch (2018); Asoka et al. (2013); PRB (2020); CEA (2020)
1.2	Aging population	Kuhnimhof et al. (2012); Blumenburg et al. (2012); NCES (2020)
2	**Change in socioeconomic status**	Gardoni and Murphy (2018); CEA (2020)
2.1	Change in income	Zhou et al. (2012);Litman (2006);Paulley et al. (2006); CEA (2020)
2.2	Change in housing value	Has et al. (2016); Saberi et al. (2017); CEA (2020, Leonard et al. (2016); Reichert 1990); Manchester (1987)
2.3	Change in employment rate	Jiwattanakulpaisarn et al. (2009);Gardoni and Murphy (2018); CEA (2020);

3	**Change in aesthetic preferences**	Chen and Duan (2014); Valdes-Vasquez and Klotz (2012);Ugwu et al. (2006); Pugach et al. (2017)
4	**Change in land use patterns**	Litman (2006);Lee et al. (2015); Ralph et al. 1999); Briassoulis, H. (2009); Hasse and Lathrop (2003)
5	**Change in legislation and policies (e.g., on travel safety, emergency service response)**	Ingram et al. (2009); Klatter et al. (2009); Haghshenas et al. (2015); Stonemeier et al. (2016)
6	**Change in risk tolerance**	Li (2019)
7	**Change in labor market (e.g., lack of skilled labor)**	Bureau of labor statistics (2020); Fox Business (2020); Forbes (2020)
8	**Change in perceptions on careers (e.g., engineers become a less popular career)**	Bureau of labor statistics (2020)
9	**Education on new technical knowledge**	US Department of Education (2020)
	Economic Factor	
1	**Economic growth**	Circella et al. (2016); Ecola and Wachs (2012); fairmontequities (2020); world bank (2020)
2	**Change in fuel price**	Hakimelahi et al. (2016); Lin and Prince (2013); Odeck and Johansen (2016); Circella et al. (2016); EIA (2020); stlouisfed (2020); kalibrate (2020); americanscientists (2020)
3	**E-commerce growth**	Rutter et al. (2017); oberlo (2020)
4	**Change in road pricing (i.e., toll)**	Wang and Zhang (2017); Brinckerhoff et al. (2012);Litman (2019); USDOT (2020); Kim et al. (2013);
5	**Globalization and trade war**	Kempe (2019); Pomeroy (2019); europa (2020); oecd (2020); Guillén, M. (2001)
6	**Availability of funding (e.g., federal, state, local, private)**	Bridge Masters (2018); Hewett (2017, Podkul (2011; Hargreaves (2012); statista (2020);
7	**Public-private partnership trend**	Mallet (2017); Sadasivam et al. (2016); Lammam et al. (2013), Bhatia (2010)
8	**Change in construction cost**	AASHTO (2014);Aboutaha and Zhang (2016);MDOT (2018), Akintoye (2010)
9	**Change in taxation**	Constrcutiondrive (2020)
	Technological Factor	
1	**New transportation facilities or methods**	Maoyanda (2019); Karsten and Ashok (2019); Cunningham (2017); Fox News (2013)
1.1	Hyperloop	Cunningham (2017); Fox News (2013); Maoyanda (2019, Werner (2016)
1.2	Automated and connected vehicles	Fox News (2013); Cunningham (2017); Sener (2016)
1.3	Shared mobility	Clewlow (2018); McCoy et al. (2018); Werner (2014)
1.4	Urban transport pod	Fox News (2013); Cunningham (2017); Schottle (2018)
1.5	Maglev train	Maoyanda (2019; Yasuda (2010)
2	**Interference between human and traffic**	Sohrweide (2018); Marshall (2017); Johns (2018); Borenstein et al (2017); Duarte and Ratti (2018)
2.1	Communications between vehicles and road infrastructure	Sohrweide (2018); Borenstein et al. (2019)
2.2	Advanced computing system for navigation	Marshall (2017); Johns (2018)
3	**Adoption of new construction materials or structures**	Allis (2016); Housely (2019); CONEXPO (2019)
3.1	Adoption of thermoplastic materials	Housely (2019); Biron (2018)
3.2	Adoption of composite materials	Allis (2016); Lomax and Duffy (2013, Pervaiz (2016)

3.3	Adoption of geosynthetic reinforced soil-integrated bridge system	CONEXPO (2019); FHWA 2020;
3.4	Adoption of high performance steel	Barker and Schrage 2000
3.5	Adoption of ultrahigh-performance concrete	Modorintelligence 2020
3.6	Adoption of elastomeric bridge bearing	Tranparency market research 2020
4	**Adoption of new construction techniques**	Allis (2016 ; Housely (2019); Lomax and Duffy (2013); FHA (2013); Bridge Masters (2019)
4.1	Adoption of accelerated bridge construction technology	Allis (2016); Housely (2019), Wang (2013)
4.2	Adoption of slide-in bridge construction	UDOT (2013); Jacobsen (2001)
4.3	Adoption of Self-Propelled Modular Transporters (SPMTs) in bridge construction	FHWA 2020;
5	**Advancement in structural health monitoring techniques**	Housley (2019); Lynch et al (2016) ; Zhu et al (2018); Bas et al (2017)
5.1	Acoustic Imaging for inspecting substructure	Housley (2019);Bas et al. (2017)
5.2	Smart sensors for active monitoring	Lynch et al. (2016); Zhu et al. (2018)
5.3	Machine learning for structural health prediction	Farar and Warden (2012)
6	**Change in ways of communication**	O'Brien and Al-Souf 1994); Rezgui et al (2010)

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Appendix B

INTERVIEW GUIDE

Version: Nov 15, 2019

Interviewer:	
Date:	
Place:	
Starting Time:	
Interviewee/ Pseudonym:	
Interviewee Occupation:	

A. INTERVIEW QUESTIONS

Introduction

Thank you for accepting this expert interview. We really appreciate it. We are working on a research project that focuses on understanding the critical impacting factors or trends that could affect the design, construction, and maintenance of bridges in the future. For example, climate change, technological advancement, and etc. In this expert interview, we look forward to hearing your opinions in terms of (1) what the potential impacting factors are, and (2) how they are going to affect bridge design, construction and maintenance. We would also like to discuss about ABC in particular.

Before we get started, can you please also introduce your own background so I can try to tailor my questions accordingly?

Bridge Design

1. Based on your expertise in Bridge Engineering, what are the critical factors that could affect the design standards of our future bridges?
2. Can you explain why you believe the factors could affect the design standards of future bridges?
3. Can you explain how these factors could affect the design standards of future bridges?
4. How do you predict the trends of the factors you mentioned? / Do you see any particular trends in the factors you just mentioned?
5. Among the factors you discussed, what are the factors that you believe are the most critical ones?
6. What are the factors you have already accounted for in the design of bridges?

Bridge Construction

1. What are the critical factors that could affect the construction processes of our future bridges?
2. Can you explain why you believe the factors could affect the construction processes of future bridges?

3. Can you explain how these factors could affect the construction processes of future bridges?
4. How do you predict the trends of the factors you mentioned?
5. Among the factors you discussed, what are the factors that you believe are the most critical ones?
6. What are the factors you have already accounted for in the construction of bridges?

Bridge Maintenance

1. What are the critical factors that could affect the maintenance of our future bridges?
2. Can you explain why you believe the factors could affect the maintenance of future bridges?
3. Can you explain how these factors could affect the maintenance of future bridges?
4. How do you predict the trends of the factors you mentioned?
5. Among the factors you discussed, what are the factors that you believe are the most critical ones?
6. What are the factors you have already accounted for in the maintenance of bridges?

ABC

1. What are the critical factors that could affect ABC in particular?
2. Can you explain why you believe the factors could affect ABC?
3. Can you explain how these factors could affect ABC?

Conclusions

Now before we end this interview, is there anything that you would like to add or discuss about? Thank you for your time.

B. DEMOGRAPHICS

Please fill out the following section about your background.

F1. How old are you?

- ☐ 18-25
- ☐ 26-30
- ☐ 31-35
- ☐ 36-40
- ☐ 41-45
- ☐ 46-50
- ☐ 51-55
- ☐ 56-60
- ☐ 61-65
- ☐ Above 65

F2. What is the highest degree of level of school you have completed? If you are currently enrolled, please mark the previous grade or highest degree received.

- ☐ Less than 12th grade
- ☐ 12th grade, no diploma
- ☐ High school graduate- high school diploma or the equivalent (for example: GED)
- ☐ Some college credit, no degree
- ☐ Associate degree (e.g., AA, AS)
- ☐ Bachelor's degree
- ☐ Graduate degree
- ☐ Professional degree (e.g., MD, JD)
- ☐ Other (please specify) ___________________________________

F3. Are you Spanish, Hispanic, or Latino?

- ☐ Yes
- ☐ Not Spanish, Hispanic or Latino

F4. Could you please specify your race?

- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ White
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ Do not know
- ☐ Other (please specify) ___________________________________

F5. Please mark your gender below.

- ☐ Male
- ☐ Female

F6. Do you work?

- [ ] Yes
- [ ] No

F7. If you do work, how long have you been working in your current work place?

- [ ] Less than 1 year
- [ ] More than 1 year but less than 3 years
- [ ] More than 3 years but less than 6 years
- [ ] More than 6 years but less than 9 years
- [ ] More than 9 years but less than 12 years
- [ ] 12 years or more

F8. In which state do you currently reside?

____

We are at the end of our interview. Do you have any questions for me or anything you would like to talk about that I have not asked about?

Also, if it is OK with you, I would like you to suggest a few individuals for me to contact. These individuals could be bridge experts in the industry, academia, or government.

THANK YOU VERY MUCH FOR YOUR PARTICIPATION

Appendix C

#	Factors	Indicators	Trends
		Environmental Factor	
1	**Change in temperature**	Annual Average Temperature	Increasing
1.1	Change in extreme maximum temperature	Annual Maximum Temperature	Increasing
1.2	Change in range of max and min temperatures	Extremes in Maximum Temperatures, Extremes in Minimum Temperatures	Increasing (min. increasing faster)
2	**Change in relative humidity**	Relative Humidity	Increasing
3	**Change in precipitation**		Increasing
3.1	Change in overall precipitation	Average Annual Precipitation	Increasing
3.2	Increased intense precipitation	Annual Heavy Downpour	Increasing
4	**Sea level rise**	Mean Sea Level	Increasing
5	**Change in intensity and frequency of extreme events (e.g., hurricanes, flooding, earthquakes)**		Increasing
5.1	Stronger wind loads	Near-Surface Wind Speeds	Increasing
5.2	Greater storm surges	Tropical Cyclone, Extratropical Cyclones	Increasing
5.3	More frequent earthquakes	Frequency of occurrence	Increasing
6	**Change in air quality**	Air Quality Index, Ground-Level Ozone,	Increasing
6.1	Increased GHG and CO2 emission	Annual Greenhouse Gas Index, GHG Intensity	Increasing
6.2	Atmospheric pollutants (e.g., sulphates, chlorides)	Criteria Air Pollutants, Net Calorific Value	Increasing
7	**Change in soil quality (e.g., soil salinity)**	Particulate Organic Matter	Decreasing
8	**Change in water quality**	COD, BOD, TOC, TIC, pH	COD-Increasing, BOD-Decreasing
		Social Factor	
1	**Change in demographic features**	Population Density, Total Population	Increasing
1.1	Change in population growth rate	Percent Population Change, Net Migration	Increasing
1.2	Aging population	Age Distribution	No change
2	**Change in socioeconomic status**	Minority Population, Participation in Literacy	Increasing
2.1	Change in income	Unemployment Rate	Decreasing
2.2	Change in housing value	Homeownership Rate	Decreasing
2.3	Change in employment rate	Median Usual Weekly Earnings	Increasing
3	**Change in aesthetic preferences**	Visual Aesthetics, Cognitive Pragmatics,	Varying
4	**Change in land use patterns**	Population Density, Density of Urbanization	Increasing
5	**Change in legislation and policies**	Policy Alignment, Stakeholder Engagement	Increasing
6	**Change in risk tolerance**	Tolerance Level	Decreasing
7	**Change in labor market (e.g., lack of skilled labor)**	Gross Job Losses	Increasing
8	**Change in perceptions on careers (e.g., engineers become a less popular career)**	Employment rate	Increasing

9	**Education on new technical knowledge**	CTE participation rate	Varying
Economic Factor			
1	**Economic growth**	GDP Growth, GNP Growth	Increasing
2	**Change in fuel price**	Global Demand, Annual Consumption	Increasing
3	**E-commerce growth**	Customer Acquisition Cost (CAC), Average Order Value (AOV)	Increasing
4	**Change in road pricing (i.e., toll)**	Congestion Charge, Zone-Based Charges	Increasing
5	**Globalization and trade war**	Foreign Direct Investment (FDI),	Decreasing
6	**Availability of funding (e.g., federal, state, local, private)**	Investment Rate	Increasing
7	**Public-private partnership trend**	Annual Investment	Increasing
8	**Change in construction cost**	Tender Price Index	Increasing
9	**Change in taxation**	Federal, state, and local tax rate	Increasing
Technological Factor			
1	**New transportation facilities or methods**		
1.1	Hyperloop	Shared Value Potential	Increasing
1.2	Automated and connected vehicles	Consumer Acceptance	Increasing
1.3	Shared mobility	Shared Value Potential	Increasing
1.4	Urban transport pod	Mobility Trend	Increasing
1.5	Maglev train	Travel Demand	Increasing
2	**Interference between human and traffic**		
2.1	Communications between vehicles and road infrastructure	Vehicle-Miles of Travel (VMT)	Increasing
2.2	Advanced computing system for navigation	ITS Intensity	Increasing
3	**Adoption of new construction materials or structures**		
3.1	Adoption of thermoplastic materials	Market Demand	Increasing
3.2	Adoption of composite materials	Market Demand	Increasing
3.3	Adoption of geosynthetic reinforced soil-integrated bridge system	Current State of Practice	Increasing
3.4	Adoption of high-performance steel	Current State of Practice	Increasing
3.5	Adoption of ultrahigh-performance concrete	Market growth	Increasing
3.6	Adoption of elastomeric bridge bearing	Market growth trajectory	Increasing
4	**Adoption of new construction techniques**		
4.1	Adoption of accelerated bridge construction technology	Decision Scope	Increasing
4.2	Adoption of slide-in bridge construction	Decision Scope	Increasing
4.3	Adoption of Self-Propelled Modular Transporters (SPMTs) in bridge construction	Decision scope	Increasing
5	**Advancement in structural health monitoring techniques**		
5.1	Acoustic Imaging for inspecting substructure	Market Demand	Increasing
5.2	Smart sensors for active monitoring	Market Demand	Increasing
5.3	Machine learning for structural health prediction	Market Demand, Knowledge Improvement	Increasing
6	**Change in ways of communication**	Knowledge Management, Electronic Data Interchange	Increasing

Appendix D

Appendix D

Understanding Critical Impacting Factors and Trends on Bridge Design, Construction, and Maintenance for Future Planning

Start of Block: Overview

PURPOSE OF THE STUDY
The purpose of this study is to understand the trends of critical impacting factors and examine how these factors may impact the way that bridges are designed, constructed, and maintained in the future (10-30 years).
DURATION OF THE STUDY
Your participation will take about 10 minutes.
RISKS
This study will not involve sensitive topic, pose risks, or interrupt with your daily activities. You can refuse to answer any question that you do not feel comfortable answering or stop at any time during the course of the study.
BENEFITS
This project will advance the understanding of the critical impacting factors and their trends, as well as the potential interactions among the factors and bridge design, construction and maintenance.
USE OF YOUR INFORMATION
We will remove identifiers about you from our data. When the results of the research are published or discussed in conferences or used for educational purposes, we will not include any information that would reveal your identity.
CONFIDENTIALITY
We will keep the records of this study private and protect to the fullest extent provided by law. In any sort of report we might publish, we will not include any information that will make it possible to identify you. We will store research records securely, and allow only the research team to have access to the records.
RIGHT TO DECLINE OR WITHDRAW
Your participation in this study is voluntary. You are free to participate in the study or withdraw your consent at any time during the study. You will not lose any benefits if you decide not to participate or if you quit the study early.
IRB CONTACT INFORMATION
If you would like to talk with someone about your rights of being a subject in this research study or about ethical issues with this research study, you may contact the FIU Office of Research Integrity by phone at 305-348-2494 or by email at ori@fiu.edu.
PARTICIPANT AGREEMENT
I have read the information in this consent form and agree to participate in this study. By clicking on the arrow button below I am providing my informed consent.
RESEARCHER CONTACT INFORMATION
If you have any questions about the purpose, procedures, or any other issues relating to this research study you may contact Lu Zhang at 10555 West Flagler Street, EC 2935, Miami, FL 33174, (305)-348-7227, luzhang@fiu.edu.

End of Block: Overview

Start of Block: bridge factor impact

Section 1. Impact Assessment

For each of the following trends or factors, please indicate how likely they could IMPACT bridge design, construction, and maintenance in the future (10-30 years).

Environmental Trends or Factors

	Extremely Likely (1)	Very Likely (2)	Likely (3)	Not Likely (4)	No Impact (5)
Change in temperature (e.g., increase in average annual temperature, more frequent extreme temperatures) (1)	○	○	○	○	○
Change in relative humidity (e.g., climate change casues increase in humidity level) (4)	○	○	○	○	○
Change in precipitation (e.g. increase in average annual precipitation) (5)	○	○	○	○	○
Sea level rise (7)	○	○	○	○	○
Change in intensity and frequency of extreme events (e.g., more frequent or more intense hurricanes, floods, earthquakes) (8)	○	○	○	○	○
Change in air quality (e.g., increase in green house gas emissions or atmospheric pollutants) (10)	○	○	○	○	○
Change in soil quality (e.g., increase in soil salinity, heavy metals and pollutants) (12)	○	○	○	○	○

Change in water quality (e.g., increase in average salinity, turbidity, acidity, and water pollutants) (13)	○	○	○	○	○

Social Trends or Factors

	Extremely Likely (2)	Very Likely (7)	Likely (8)	Not Likely (9)	No Impact (10)
Change in demographic features (e.g., increase in population growth, aging population) (1)	○	○	○	○	○
Change in socioeconomic status (e.g., increase in income, employment rate, housing value) (3)	○	○	○	○	○
Change in aesthetic preferences (e.g., architectural design of bridges) (8)	○	○	○	○	○
Change in land use patterns (e.g., increase in urban density, road networks) (9)	○	○	○	○	○
Change in legislation and policies (e.g., more stringent requirements on travel safety) (10)	○	○	○	○	○
Change in risk tolerance (e.g., increase in safety precautions) (13)	○	○	○	○	○
Change in labor market (e.g., shortage of skilled labor) (15)	○	○	○	○	○

Change in perceptions on careers (e.g., less popularity of engineering careers) (16)	○	○	○	○	○
Education on new technical knowledge (e.g., training engineers on new technologies) (18)	○	○	○	○	○

Economic Trends or Factors

	Extremely Likely (1)	Very Likely (2)	Likely (3)	Not Likely (7)	No Impact (4)
Economic change (e.g., increase in GDP, GNP) (1)	○	○	○	○	○
Fuel price drop (2)	○	○	○	○	○
E-commerce growth (3)	○	○	○	○	○
Change in road pricing (i.e., increase in toll charges, congestion charges) (4)	○	○	○	○	○
Globalization and trade war (e.g., increase in foreign direct investments) (5)	○	○	○	○	○
Availability of funding (e.g., federal, state, local, private funding) (6)	○	○	○	○	○
Public-private partnership trend (e.g., increase in average annual investments in public-private partnership) (7)	○	○	○	○	○
Change in construction cost (e.g.,	○	○	○	○	○

increase in overall construction costs) (8)					
Change in taxation (e.g., decrease in federal tax rate on construction) (9)	○	○	○	○	○

Technological Trends or Factors

	Extremely Likely (1)	Very Likely (2)	Likely (7)	Not Likely (8)	No Impact (9)
New transportation facilities or methods (e.g., Automated vehicles, Shared mobility, Hyperloop) (1)	○	○	○	○	○
Interference between human and traffic (e.g., communications between vehicles and road infrastructure, advanced navigation system) (6)	○	○	○	○	○
Adoption of new construction materials or structures (e.g., thermoplastic and composite materials, high performance steel, ultra-high performance concrete, elastomeric bridge bearing) (8)	○	○	○	○	○
Adoption of new construction techniques (e.g., slide-in bridge construction, use of Self Propelled Modular Transporters) (12)	○	○	○	○	○
Advancement in bridge health monitoring and maintenance (e.g., drones, acoustic imaging, smart sensors, machine learning for structural health prediction) (13)	○	○	○	○	○
Change in ways of management and	○	○	○	○	○

communication (e.g., building information modeling, cloud-based management software or tools, digital supply chain management platforms) (15)	

Please select which of the trends or factors might have significant impact on **Accelerated Bridge Construction**.

☐ **Change in temperature** (e.g., increase in average annual temperature, more frequent extreme temperatures) (1)

☐ **Change in relative humidity** (e.g., climate change casues increase in humidity level) (2)

☐ **Change in precipitation** (e.g. increase in average annual precipitation) (3)

☐ **Sea level rise** (4)

☐ **Change in intensity and frequency of extreme events** (e.g., more frequent or more intense hurricanes, floods, earthquakes) (5)

☐ **Change in air quality** (e.g., increase in green house gas emissions or atmospheric pollutants) (6)

☐ **Change in soil quality** (e.g., increase in soil salinity, heavy metals and pollutants) (7)

☐ **Change in water quality** (e.g., increase in average salinity, turbidity, acidity, and water pollutants) (8)

☐ **Change in demographic features** (e.g., increase in population growth, aging population) (9)

☐ **Change in socioeconomic status** (e.g., increase in income, employment rate, housing value) (10)

☐ **Change in aesthetic preferences** (e.g., architectural design of bridges) (11)

☐ **Change in land use patterns** (e.g., increase in urban density, road networks) (12)

☐ **Change in legislation and policies** (e.g., more stringent requirements on travel safety) (13)

☐ **Change in risk tolerance** (e.g., increase in safety precautions) (14)

☐ **Change in labor market** (e.g., shortage of skilled labor) (15)

☐ **Change in perceptions on careers** (e.g., less popularity of engineering careers) (16)

☐ **Education on new technical knowledge** (e.g., training engineers on new technologies) (17)

☐ **Economic growth** (e.g., increase in GDP, GNP) (18)

☐ **Fuel price drop** (19)

☐ **E-commerce growth** (20)

☐ **Change in road pricing** (i.e., increase in toll charges, congestion charges) (21)

☐ **Globalization and trade war** (e.g., increase in foreign direct investments) (22)

☐ **Availability of funding** (e.g., federal, state, local, private funding) (23)

☐ **Public-private partnership trend** (e.g., increase in average annual investments in public-private partnership) (24)

☐ **Change in construction cost** (e.g., increase in overall construction costs) (25)

☐ **Change in taxation** (e.g., decrease in federal tax rate on construction) (26)

☐ **New transportation facilities or methods** (e.g., Automated vehicles, Shared mobility, Hyperloop) (27)

☐ **Interference between human and traffic** (e.g., communications between vehicles and road infrastructure, advanced navigation system) (28)

☐ **Adoption of new construction materials or structures** (e.g., thermoplastic and composite materials, high performance steel, ultrahigh-performance concrete, elastomeric bridge bearing) (29)

☐ **Adoption of new construction techniques** (e.g., slide-in bridge construction, use of Self Propelled Modular Transporters) (30)

☐ **Advancement in bridge health monitoring and maintenance** (e.g., drones, acoustic imaging, smart sensors, machine learning for structural health prediction) (31)

☐ **Change in ways of management and communication** (e.g., building information modeling, cloud-based management software or tools, digital supply chain management platforms) (32)

End of Block: bridge factor impact

Start of Block: trend new

Section 2. Trend Analysis

For the same list of trends or factors, please indicate how you think they will PROGRESS within the next 10 to 30 years.

Environmental Trends or Factors

	Trend continues (1)	Trend stops (2)	Trend reverses (3)	Unpredictable trend (4)
Change in temperature (e.g., increase in average annual temperature, more frequent extreme temperatures) (1)	○	○	○	○
Change in relative humidity (e.g., climate change casues increase in humidity level) (4)	○	○	○	○
Change in precipitation (e.g. increase in average annual precipitation) (5)	○	○	○	○
Sea level rise (7)	○	○	○	○
Change in intensity and frequency of extreme events (e.g., more frequent or more intense hurricanes, floods, earthquakes) (8)	○	○	○	○
Change in air quality (e.g., increase in green house gas emissions or atmospheric pollutants) (10)	○	○	○	○
Change in soil quality (e.g., increase in soil salinity, heavy metals and pollutants) (12)	○	○	○	○

Change in water quality (e.g., increase in average salinity, turbidity, acidity, water pollutants) (13)	○	○	○	○

Social Trends or Factors

	Trend continues (2)	Trend stops (7)	Trend reverses (8)	Unpredictable trend (9)
Change in demographic features (e.g., increase in population growth, aging population) (1)	○	○	○	○
Change in socioeconomic status (e.g., increase in income, employment rate, housing value) (3)	○	○	○	○
Change in aesthetic preferences (e.g., architectural design of bridges) (8)	○	○	○	○
Change in land use patterns (e.g., increase in urban density, road networks) (9)	○	○	○	○
Change in legislation and policies (e.g., more stringent requirements on travel safety) (10)	○	○	○	○
Change in risk tolerance (e.g., increase in safety precautions) (13)	○	○	○	○
Change in labor market (e.g., shortage of skilled labor) (15)	○	○	○	○

Change in perceptions on careers (e.g., less popularity of engineering careers) (16)	○	○	○	○
Education on new technical knowledge (e.g., training engineers on new technologies) (18)	○	○	○	○

Economic Trends or Factors

	Trend continues (1)	Trend stops (2)	Trend reverses (3)	Unpredictable trend (7)
Economic growth (e.g., increase in GDP, GNP) (1)	○	○	○	○
Fuel price drop (2)	○	○	○	○
E-commerce growth (3)	○	○	○	○
Change in road pricing (i.e., increase in toll charges, congestion charges) (4)	○	○	○	○
Globalization and trade war (e.g., increase in foreign direct investments) (5)	○	○	○	○
Availability of funding (e.g., federal, state, local, private funding) (6)	○	○	○	○
Public-private partnership trend (e.g., increase in average annual investments in public-private partnership) (7)	○	○	○	○
Change in construction cost (e.g., increase in overall construction costs) (8)	○	○	○	○

Change in taxation (e.g., decrease in federal tax rate on construction) (9)	○	○	○	○

Technological Trends or Factors

	Trend continues (1)	Trend stops (2)	Trend reverses (7)	Unpredictable trend (8)
New transportation facilities or methods (e.g., Automated vehicles, Shared mobility, Hyperloop) (1)	○	○	○	○
Interference between human and traffic (e.g., communications between vehicles and road infrastructure, advanced navigation system) (6)	○	○	○	○
Adoption of new construction materials or structures (e.g., thermoplastic and composite materials, high performance steel, ultrahigh-performance concrete, elastomeric bridge bearing) (8)	○	○	○	○
Adoption of new construction techniques (e.g., slide-in bridge construction, use of Self Propelled Modular Transporters) (12)	○	○	○	○
Advancement in bridge health monitoring and maintenance (e.g., drones, acoustic imaging, smart sensors, machine learning for structural health prediction) (13)	○	○	○	○
Change in ways of management and	○	○	○	○

communication (e.g., building information modeling, cloud-based management software or tools, digital supply chain management platforms) (15)	

End of Block: trend new

Start of Block: background info

Section 3. Background Information

In order to understand the perspective of each respondent, we need to collect some basic information about you. All of this information is completely confidential and cannot be used to identify an individual respondent.

How old are you?

- 18-25 (1)
- 26-30 (2)
- 31-35 (3)
- 36-40 (4)
- 41-45 (5)
- 46-50 (6)
- 51-55 (7)
- 56-60 (31)
- 61-65 (8)
- Above 65 (9)

What is your gender?

- Male (1)
- Female (2)

Are you Spanish, Hispanic, or Latino?

- Yes (1)
- Not Spanish, Hispanic or Latino (2)

Could you please specify your race?

- ○ American Indian or Alaska Native (1)
- ○ Asia (2)
- ○ White (3)
- ○ Black or African American (4)
- ○ Native Hawaiian or Other Pacific Islander (5)
- ○ Do not know (6)
- ○ Other (please specify) (7) ____

What is the highest degree of level of school you have completed? If you are currently enrolled, please mark the previous grade or highest degree received.

- ○ Less than 12th Grade (1)
- ○ High school graduate- high school diploma or the equivalent (for example: GED) (3)
- ○ Some college credit, no degree (4)
- ○ Associate degree (e.g., AA, AS) (5)
- ○ Bachelor's degree (6)
- ○ Graduate degree (7)
- ○ Professional degree (e.g., MD, JD) (8)
- ○ Other (please specify) (9) ____

Where are you employed?

○ PRIVATE-FOR-PROFIT company, business or individual, for wages, salary or commissions (1)

○ NOT-FOR-PROFIT, tax-exempt, or charitable organization (2)

○ Local GOVERNMENT employee (city, county, etc.) (3)

○ State GOVERNMENT employee (4)

○ Federal GOVERNMENT employee (5)

○ SELF-EMPLOYED (6)

○ UNIVERSITY (7)

○ RESEARCH AGENCY (8)

○ Others (9) ____

What is your current position?

____

How long have you worked/been working in a position that is relevant to bridge engineering (bridge planning, design, construction, or maintenance)?

○ Less than 5 years (1)

○ 5 to 10 years (2)

○ 10 to 20 years (3)

○ 20 to 30 years (4)

○ More than 30 years (5)

In which state do you currently reside?

▼ Alabama (1) ... I do not reside in the United States (53)

Can you think of any other factors or trends that may affect bridge design, construction and maintenance in the future?

____

____

____

____

____

In the event that further information from you can help us improve our effort, may we contact you by email?

○ Yes (1)

○ No (2)

Display This Question:

If In the event that further information from you can help us improve our effort, may we contact you... = Yes

Please provide us with your email address below.

____

End of Block: background info