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

Quarterly Progress Report
For the period ending Feb 29, 2020

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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. We will further evaluate the trends 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: 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**.

Besides the interview, we have also designed a questionnaire survey. The questionnaire 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. The survey will be implemented on Qualtrics from Mar 2020 to Apr 2020. The questionnaire survey is included in **Appendix D**.

7 Task 4- Evaluation of critical impacting factors.

Proposed task description: This task aims to evaluate the research findings through an expert panel. The expert panel will be organized as part of 2020 International Accelerated Bridge Construction Conference in December 2020 to further solicit opinions from multi-sector experts (e.g., experts from academia, industry, and public agencies). The preliminary research findings will be shared with the panelists, and questions will be prepared before the panel. Some examples of questions include: (1) How would climate change affect bridge DCM? (2) How would advanced transportation technologies (e.g., CAVs) influence the travel demand on bridges and how does it

affect infrastructure investment policies? (3) How can the temporal and sectoral changes in U.S. population influence the passenger travel demands that in turn affect the bridge infrastructure management? (4) What is the range of influence of alternating economic factors, such as changes in fuel prices, trades, and budget policies, on U.S. bridges?

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

8 Task 5 – 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 will be based on consolidating the investigation and analysis of critical impacting factors from (1) literature review, (2) expert surveys and interviews, and (3) evaluations and opinions from the expert panel.

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

9 Task 6 – 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

The table below summarizes the main deliverables of each task:

Tasks	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 – Evaluation of critical impacting factors	Evaluated critical impacting factors and how they affect bridge DCM
Task 5 – Recommendations	A set of recommendations
Task 6 – Final report	Final report, audio-visual products that present research findings

Schedule

Progress of tasks in this project is shown in the table and chart below.

Item	40% Completed
Task 1 – Identification of potential impacting factors	100%
Task 2 – Understanding the trends of impacting factors	90%
Task 3 – Identification and analysis of critical impacting factors	50%
Task 4 – Evaluation of critical impacting factors	0%
Task 5 – Recommendations	0%
Task 6 – Final report	0%

Tasks	2019				2020											
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Task 1 – Identification of potential impacting factors																
Task 2 – Understanding the trends of impacting factors																
Task 3 – Identification and analysis of critical impacting factors								★								
Task 4 – Evaluation of critical impacting factors											★					
Task 5 – Recommendations																
Task 6 – Final report																★
									Work Performed							
									Work To be Performed							

Note: The stars denote the critical milestones of the project

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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
- ☐ Other (please specify) _____
- ☐ Associate degree (e.g., AA, AS)
- ☐ Bachelor's degree
- ☐ Graduate degree
- ☐ Professional degree (e.g., MD, JD)

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
- ☐ Other (please specify) _____
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ Do not know

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

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

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 5 to 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, however.

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 DCM.

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.

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.

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 “next page” button below I am providing my informed consent.

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 the future of bridge design, construction, and maintenance.

Environmental Trends or Factors

	Extremely Likely (1)	Very Likely (2)	Likely (3)	Not Likely (4)	No Impact (5)
Change in temperature (1)	○	○	○	○	○
Change in relative humidity (4)	○	○	○	○	○
Change in precipitation (5)	○	○	○	○	○
Sea level rise (7)	○	○	○	○	○
Change in intensity of extreme events (e.g., hurricanes, floods, earthquakes) (8)	○	○	○	○	○
Change in air quality (10)	○	○	○	○	○
Change in soil quality (e.g., soil salinity) (12)	○	○	○	○	○
Change in water quality (13)	○	○	○	○	○
Seismic Activity (15)	○	○	○	○	○

Social Trends or Factors

	Extremely Likely (2)	Very Likely (7)	Likely (8)	Not Likely (9)	No Impact (10)
Change in population growth rate (1)	○	○	○	○	○
Change in income (3)	○	○	○	○	○
Change in employment rate (5)	○	○	○	○	○
Availability of skilled labor (6)	○	○	○	○	○
Change in aesthetic preferences (8)	○	○	○	○	○
Change in land use patterns (9)	○	○	○	○	○
Change in legislation and policies (10)	○	○	○	○	○
Change in travel Demand (13)	○	○	○	○	○
Public opinion (15)	○	○	○	○	○
Traffic Safety (16)	○	○	○	○	○

Economic Trends or Factors

	Extremely Likely (1)	Very Likely (2)	Likely (3)	Not Likely (7)	No Impact (4)
Economic growth (1)	○	○	○	○	○
Change in fuel price (2)	○	○	○	○	○
E-commerce growth (3)	○	○	○	○	○
Change in road pricing (i.e., toll) (4)	○	○	○	○	○
Globalization and trade war (5)	○	○	○	○	○
Availability of funding (e.g., federal, state, local, private) (6)	○	○	○	○	○
Public-private partnership trend (7)	○	○	○	○	○
Change in construction cost (8)	○	○	○	○	○
Taxation (9)	○	○	○	○	○

Technological Trends or Factors

	Extremely Likely (1)	Very Likely (2)	Likely (7)	Not Likely (8)	No Impact (9)
New transportation facilities or methods (1)	○	○	○	○	○
Interference between human and traffic (6)	○	○	○	○	○
Adoption of new construction materials or structures (8)	○	○	○	○	○
Adoption of new construction techniques (12)	○	○	○	○	○
Advancement in structural health monitoring techniques (13)	○	○	○	○	○
Time frame of construction (15)	○	○	○	○	○

End of Block: bridge factor impact

Start of Block: bridge factor trend

Q33 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 20 years.

Environmental Trends or Factors

	Trend continues (1)	Trend stops (2)	Trend reverses (3)	Unpredictable trend (4)
Change in temperature (1)	○	○	○	○
Change in relative humidity (4)	○	○	○	○
Change in precipitation (5)	○	○	○	○
Sea level rise (7)	○	○	○	○
Change in intensity of extreme events (e.g., hurricanes, floods, earthquakes) (8)	○	○	○	○
Change in air quality (10)	○	○	○	○
Change in soil quality (e.g., soil salinity) (12)	○	○	○	○
Change in water quality (13)	○	○	○	○
Seismic Activity (15)	○	○	○	○

Social Trends or Factors

	Trend continues (2)	Trend stops (7)	Trend reverses (8)	Unpredictable trend (9)
Change in population growth rate (1)	○	○	○	○
Change in income (3)	○	○	○	○
Change in employment rate (5)	○	○	○	○
Availability of skilled labor (6)	○	○	○	○
Change in aesthetic preferences (8)	○	○	○	○
Change in land use patterns (9)	○	○	○	○
Change in legislation and policies (10)	○	○	○	○
Change in travel Demand (13)	○	○	○	○
Public opinion (15)	○	○	○	○
Traffic Safety (16)	○	○	○	○

Economic Trends or Factors

	Trend continues (1)	Trend stops (2)	Trend reverses (3)	Unpredictable trend (7)
Economic growth (1)	○	○	○	○
Change in fuel price (2)	○	○	○	○
E-commerce growth (3)	○	○	○	○
Change in road pricing (i.e., toll) (4)	○	○	○	○
Globalization and trade war (5)	○	○	○	○
Availability of funding (e.g., federal, state, local, private) (6)	○	○	○	○
Public-private partnership trend (7)	○	○	○	○
Change in construction cost (8)	○	○	○	○
Taxation (9)	○	○	○	○

Technological Trends or Factors

	Trend continues (1)	Trend stops (2)	Trend reverses (7)	Unpredictable trend (8)
New transportation facilities or methods (1)	○	○	○	○
Interference between human and traffic (6)	○	○	○	○
Adoption of new construction materials or structures (8)	○	○	○	○
Adoption of new construction techniques (12)	○	○	○	○
Advancement in structural health monitoring techniques (13)	○	○	○	○
Time frame of construction (15)	○	○	○	○

End of Block: bridge factor trend

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.

Q19 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)
- 61-65 (8)
- Above 65 (9)

Q24
Please mark you gender below.

- Male (1)
- Female (2)

Q22
Are you Spanish, Hispanic, or Latino?

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

Q23 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) _____

Q21 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 tha 12th Grade (1)
- 12th grade, no diploma (2)
- 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) _____

Q38 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) _____

Q41 How long have you been working in your current position?

- ○ 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)

Q42 In which state do you currently reside?

▼ Florida (1) ... Florida (1)

If you recognize any additional factors or trends that could impact bridge design, construction and maintenance, please list the factors and their potential impacts

_____

_____

_____

_____

_____

If you would like to obtain results of our survey, please provide us with your email address below.

_____

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

- ○ Yes (1)
- ○ No (2)

End of Block: background info