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

Quarterly Progress Report
For the period ending November 30, 2019

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1. 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).

2. 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.

3. 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.

4. Description of Research Project Tasks

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

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 complete list of identified factors. We have included the table as **Appendix A**.

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: N/A

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 three 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 have contacted for more than 70 domain experts for expert interviews. The potential 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 will be in a semi-structured format, and they will be conducted in Dec 2019 to Feb 2020. We have included the interview instrument as **Appendix B**.

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 2019 International Accelerated Bridge Construction Conference in December 2019 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

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

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

5. Expected Results and Specific Deliverables

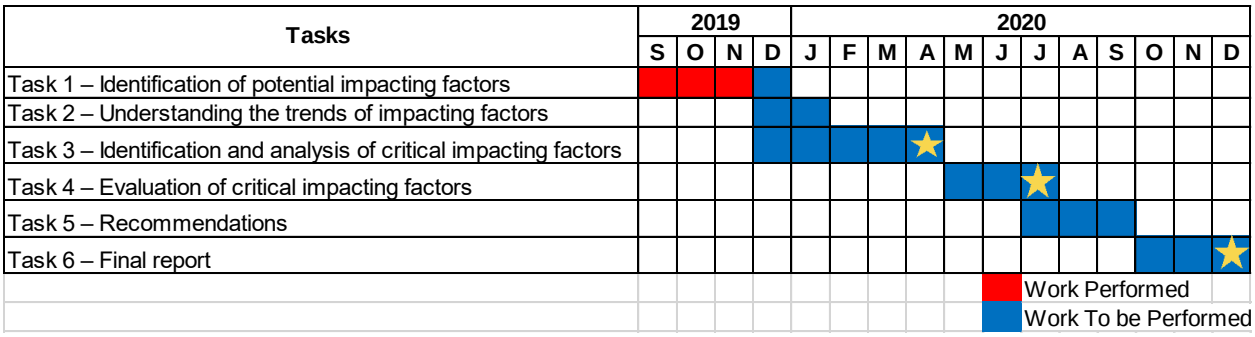
The table below summarizes the main deliverables of each task:

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

6. Schedule

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

Item	17% Completed
Task 1 – Identification of potential impacting factors	95%
Task 2 – Understanding the trends of impacting factors	0%
Task 3 – Identification and analysis of critical impacting factors	10%
Task 4 – Evaluation of critical impacting factors	0%
Task 5 – Recommendations	0%
Task 6 – Final report	0%



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Appendix A

Numbering	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)
1.1	Change in extreme maximum temperature	Rowan et al. (2013); Meyer (2008); Ballesteros-Perez et al. (2015);
1.2	Change in range of max and min temperatures	Rowan et al. (2013); Meyer (2008); Zhu et al. (2013); Regmi and Hanaoka (2011)
2	**Change in relative humidity**	Rowan et al. (2013); Nasr et al. (2019); IPCC (2013)
3	**Change in precipitation**	Rowan et al. (2013); Regmi and Hanaoka (2011); Mondoro et al. (2017); Grant (2018); IPCC (2013); Nasr et al. (2019)
3.1	Change in overall precipitation	Rowan et al. (2013); Meyer (2008), Ballesteros-Perez et al. (2015)
3.2	Increased intense precipitation	Rowan et al. (2013); Meyer (2008); Nasr et al. (2019)
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)
5	**Change in intensity of extreme events (e.g., hurricanes)**	Rowan et al. (2013); Mondoro et al. (2017); Meyer (2008); Kirshen et al. (2002); Leonard et al. (2014); IPCC (2013); Nasr et al. (2019)
5.1	Stronger wind loads	Rowan et al. (2013); Modoro et al. (2017); Ballesteros-Perez et al. (2015); Meyer (2008);
5.2	Greater Storm surges	Rowan et al. (2013); Meyer (2008); Kirshen et al. (2002)
6	**Change in air quality**	Bastidas-Arteaga et al. (2013); Stewart et al. (2012); IPCC (2013)
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)
6.2	Atmospheric pollutants (e.g., sulphates, chlorides)	Kumar and Imam (2013); Nasr et al. (2019); Wang et al. (2010)
7	**Change in soil quality (e.g., soil salinity)**	Dasgupta et al. (2015)
8	**Change in water quality**	Nasr et al. (2019); Larsen (2018)
Social Factor		
1	**Change in demographic features**	Gardoni and Murphy (2018)
1.1	Change in population growth rate	Colebatch (2018); Asoka et al. (2013)
1.2	Aging population	Kuhnimhof et al. (2012); Blumenburg et al. (2012)
2	**Change in socioeconomic status**	Gardoni and Murphy (2018)
2.1	Change in income	Zhou et al. (2012); Litman (2006); Paulley et al. (2006)
2.2	Change in housing value	Has et al. (2016); Saberi et al. (2017)
2.3	Change in employment rate	Jiwattanakulpaisarn et al. (2009); Gardoni and Murphy (2018)
3	**Change in aesthetic preferences**	Chen and Duan (2014); Valdes-Vasquez and Klotz (2012); Ugwu et al. (2006)
4	**Change in land use patterns**	Litman (2006); Lee et al. (2015)
5	**Change in legislation and policies**	Ingram et al. (2009); Klatter et al. (2009); Haghshenas et al. (2015)
Economic Factor		
1	**Economic growth**	Circella et al. (2016); Ecola and Wachs (2012)
2	**Change in fuel price**	Hakimelahi et al. (2016); Lin and Prince (2013); Odeck and Johansen (2016); Circella et al. (2016)
3	**E-commerce growth**	Rutter et al. (2017)

4	**Change in road pricing (i.e., toll)**	Wang and Zhang (2017); Brinckerhoff et al. (2012); Litman (2019)
5	**Globalization and trade war**	Kempe (2019); Pomeroy (2019)
6	**Availability of funding (e.g., federal, state, local, private)**	Bridge Masters (2018); Hewett (2017); Podkul (2011); Hargreaves (2012)
7	**Public-private partnership trend**	Mallet (2017); Sadasivam et al. (2016); Lammam et al. (2013)
8	**Change in construction cost**	AASHTO (2014); Aboutaha and Zhang (2016); MDOT (2018)
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)
1.2	Automated and connected vehicles	Fox News (2013); Cunningham (2017)
1.3	Shared mobility	Clewlow (2018); McCoy et al. (2018)
1.4	Urban transport pod	Fox News (2013); Cunningham (2017)
1.5	Maglev train	Maoyanda (2019)
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);
3.2	Adoption of composite materials	Allis (2016); Lomax and Duffy (2013)
3.3	Adoption of geosynthetic reinforced soil-integrated bridge system	CONEXPO (2019)
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)
4.2	Adoption of slide-in bridge construction	UDOT (2013)
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)

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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