REMOTE SENSING-ENHANCED NONDESTRUCTIVE EVALUATION OF ROADWAY INFRASTRUCTURE

ANALYZING THE ROADWAY INFRASTRUCTURE MAINTENANCE SYSTEMS IN THE U.S. THROUGH ACTOR-NETWORK THEORY

A Thesis Prospectus
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Approved: Date: 11/2/20
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There are over 57,000 miles of roadways maintained by the state of Virginia and the Virginia Department of Transportation (Virginia Department of Transportation [VDOT], 2019). These roadways are crucial to transportation efficiency and the daily lives of the public. Nevertheless, the state of U.S. national roadway infrastructures is subpar, with the American Society of Civil Engineers (ASCE) giving grades of D and C+ to roads and bridges, respectively, on their 2017 Infrastructure Report Card (Preston, 2020). Current methods of infrastructure evaluation can be inefficient, labor intensive, and disruptive to traffic, causing further issues with maintenance (Vary, 2019, pp. 5-7).

The technical and STS projects aim to analyze and potentially provide solutions to these issues. The technical topic explores remote sensing-enhanced nondestructive evaluation of roadway infrastructure. Tightly coupled with the technical topic is the STS topic: analyzing roadway infrastructure maintenance systems in the U.S. through the social framework of the Actor-Network Theory (ANT). The team members for the technical project are Isaac Burkhalter, Andrew Curtin, Cooper Dzema, Shane Eilers, Kevin Fletcher, Jalen Granville, Dorothea LeBeau, Colin Purcell, Bailey Roe, Khamal Saunders, Anisha Sharma, and Naja Tyree. The technical advisor is Christopher Goyne, Associate Professor and Director of the Aerospace Research Laboratory at the University of Virginia. This project is being completed in conjunction with MITRE, and in particular with CJ Rieser of the Emerging Technologies Division Office and Michael A. Balazs, the Head of Charlottesville Operations. The timetables for both the technical and STS projects are given in Table 1.

Due Date	Goal
11/2/20	Prospectus
11/4/20	Technical project end-of-semester presentation draft
11/11/20	Technical project end-of-semester report draft
11/16/20-11/18/20	Technical project end-of-semester presentation
	Prospectus presentation
11/23/20	Technical project end-of-semester report
4/21	Technical project final report and presentation

Table 1: Project Timetable. This table shows the schedule of deliverables for the technical and STS projects. (Created by Isaac Burkhalter, 2020).

REMOTE SENSING-ENHANCED NONDESTRUCTIVE EVALUATION OF ROADWAY INFRASTRUCTURE

Maintaining transportation infrastructure is vital for the wellbeing of the state and public. The collapse of bridges is extremely dangerous as shown by the death of 13 people when I-35W collapsed in Minnesota in 2007 (Vezner, 2007). Although the collapse has led to reform in how infrastructure is inspected, those methods are now dated and could be improved for more efficient and less costly methods of inspection. Research indicates that as road conditions deteriorate, there are more collisions and accidents tend to be more severe (Alhasan, Nlenanya, Smadi & MacKenzie, 2018, pp. 14-17). Currently, national regulations only enforce the inspection of roadways every five years and the inspection of bridges every two years (Gee & Henderson, 2007). Infrastructure evaluation relies heavily on this scheduling. The system for fixing roadways has become reactive, since repairs typically happen only once roads are already in poor conditions (VDOT, 2019). Current ground-based methods such as visual inspection, acoustical techniques, infrared and spectral imaging, and chemical and mechanical on-site testing of roadway infrastructure inspection are effective, but can be inefficient. These ground-based systems have many drawbacks, including traffic buildups, lane closures, and labor intensity (Vary, 2019, pp. 5-7). Additionally, they each have limitations such as potentially invalid assessment of interior infrastructure, inaccurate testing, and limited usage (McGuire, 2020).

The solution proposed could improve the inspection process by using remote-sensing enhanced nondestructive evaluation, through a combination of state-of-the-art methods that incorporate satellites, drones, and ground systems. It is hoped that air and space-based solutions will make large scale continuous monitoring of infrastructures more feasible, so that the system for fixing infrastructures can move towards a preemptive one that detects when structures begin degrading, rather than a reactive one. In addition, utilizing remote-sensing enhanced evaluation techniques could create a more efficient system for the state's roadways that would cost less, require less labor, and cause fewer transportation delays.

Research indicates there are a variety of remote sensing options available with either drones or satellites that allow for remote sensing from air and space. A paper published by Devin Harris, a Civil Engineering Professor at the University of Virginia, and other contributors says "[r]emote sensing technologies can be used to assess and monitor the condition of bridge infrastructure and improve the efficiency of inspection, repair, and rehabilitation efforts". The paper discusses the wide variety of sensors that can be utilized in the technical project, including synthetic aperture radar (SAR), interferometric synthetic aperture radar (InSAR) on satellites, light detection and ranging (LIDAR), optical sensors, acoustics sensors, and thermal and spectral sensors, among others (Vaghefi et. al, 2012, pp. 888-892). Vaghefi et. al (2012) analyze the uses and efficacy of each sensor for the detection of various different surface and subsurface defects (pp. 888-892). A tabular representation of this information is shown in Figure A1 in Appendix A. The approach to the project will involve further literature review of the state-of-the-art and consultation with subject matter experts and stakeholders to determine how these and other sensors can be outfitted to satellite, drone, and ground systems to evaluate infrastructures. Through this, it will be determined how each of the three can be specifically utilized and organized into an interconnected system to provide the most effective solution.

The end goal of the project is to present a technical report to collaborators at MITRE, and potentially other interested stakeholders, detailing a fully developed solution to the infrastructure problems described. The project focuses solely on a conceptual development of the solution, so no material resources are currently required. The scope of the solution will be at a state-wide level with the potential to expand into the national scale, so if the project continues in future years, funding may become available from MITRE or other interested parties such as the Virginia Department of Transportation.

CONFLICTING INTERESTS OF POLICY MAKERS AND THE GENERAL PUBLIC IN INFRASTRUCTURE MAINTENANCE IN THE U.S.

Historically, roadway infrastructure work has focused on expansion rather than maintenance (U.S. Department of Transportation, Federal Highway Administration [US DOT, FHA], 2012). Since 2017, however, increases in road travel have outpaced increases in new roads to the tune of 17% to 5%, respectively (Preston, 2020). Preston only mentions statistics since 2017, but the trend he describes has been ongoing since well before then. Due to this increase in travel, in combination with the nation's aging infrastructure and a historical lack of focus on maintenance, roadways are falling more and more into a state of disrepair. In 2017, Preston (2020) states that "45% of the nation's roads were deemed in poor condition" according to the ASCE's annual Infrastructure Report Card. This issue has significant ramifications across many different social groups in the U.S., as depicted in Figure 2.

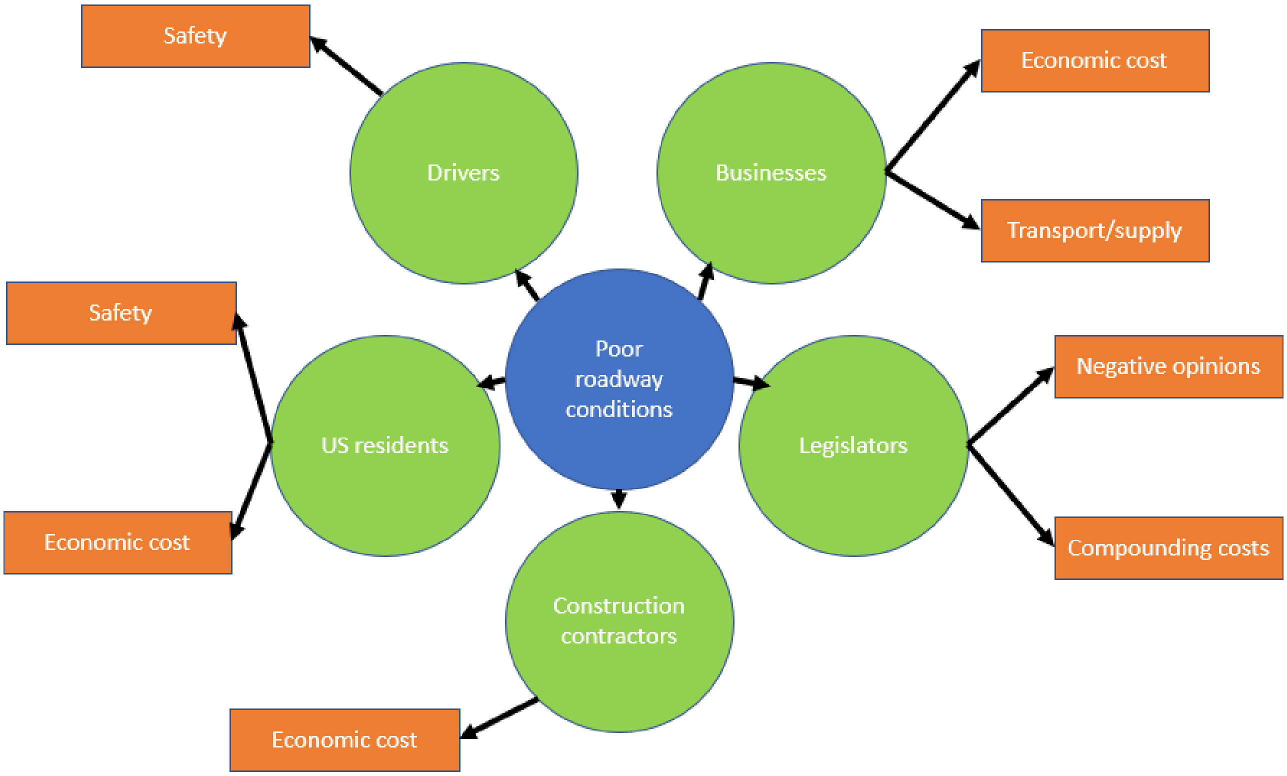

Figure 2: The Effect of Poor Roadway Conditions on Relevant Social Groups in the U.S. This figure depicts the effects of poor roadway conditions on important social groups involved in or affected by the U.S. roadway maintenance system. (Created by Isaac Burkhalter, 2020).

Having a good system is beneficial to drivers and U.S. residents from a safety perspective, as Alhasan et. al (2018) indicate that there is a significant increase in the severity of car accidents as roadway conditions deteriorate (pp.14-17). Roadway conditions have economic ramifications as well. For drivers, crashes incur an equivalent cost of $784 on every American per year (US GPO, 2019, p. 122). With respect to legislators and U.S. society as a whole, crashes “impose a financial toll of over $800 billion in total costs to society and $242 billion in direct economic costs” annually (U.S. Government Publishing Office [US GPO], 2019, p. 122). Businesses incur an economic cost as well, since poor roads stimy transport and supply capabilities. The evidence suggests that poor roadway conditions, caused by failures in the roadway maintenance system, have overwhelmingly negative effects across the board.

Because of the widespread negative effects of roadway infrastructure, the need to improve infrastructure is a rare issue that is agreed upon across party lines. Nevertheless, there are many modern examples of public policy going against public interest. For example, in 2019, the Trump administration requested $63 million less than the amount authorized for spending by Congress under the Fixing America's Surface Transportation (FAST) Act. In the same year, the budgets for roadway enforcement and rulemaking were also cut by $13.5 and $2.4 million, respectively (US GPO, 2019, p. 125). To understand the reasons behind this apparent paradox, it is necessary to understand the nature of the relationships between the social groups relevant in roadway maintenance. To this end, the STS project will focus on analyzing why conflicts of interests arise between the general public and legislators in the development of infrastructure policy by using Actor-Network Theory (ANT). ANT is "a framework and systematic way to consider the infrastructure surrounding technological achievements" that "[a]ssigns agency to both human and non-human actors" (Learning Theories, n.d.). Figure 3 shows a graphic of some of the expectations of actors important to the roadway maintenance system.

Actors		Expectations	Audience
Members of the general public with an interest in infrastructure maintenance	Drivers	Maintenance of roadways to ensure safety	U.S. residents of driving age, pedestrians, other parties at-risk of motor dangers
	Taxpayers	Funding for maintenance for safety/economic interests, but may have other interests that discourage fund allocation	Salaried U.S. residents, federal and state legislatures
	Voters	Maintenance of roadways as agreed on across party lines, but may have competing interests that take focus away from issue	U.S. citizens over 18, federal and state legislatures
Parties with an economic interest in infrastructure maintenance	Contractors	Want maintenance for business & economic benefit	Stakeholders, contract holders, clients
	Businesses	Want infrastructure maintained to ensure transportation abilities	Stakeholders, customers/clients
	Transporting services	Want infrastructure maintained for ease of transportation, economic opportunity from businesses	Businesses & consumers/clients
Institutional actors	Federal legislature	Need to balance voter interest, party lines, and allocation of funds and efforts to other issues	U.S. residents, contractors, enforcement agencies
	Federal enforcement agencies	Need to enforce laws passed by legislature pertaining to maintenance	U.S. residents, contractors, drivers
	State legislature	Need to balance voter interest, party lines, and allocation of funds and efforts to other issues	State residents, contractors, enforcement agencies
	State enforcement agencies	Need to enforce laws passed by legislature pertaining to maintenance	State residents, contractors, drivers

Figure 3: Actors and Their Expectations Pertaining to Infrastructure Maintenance. This figure shows some of the actors, their expectations, and audiences as pertaining to the issue of conflicts of interest in the U.S. infrastructure maintenance system. (Adapted by Isaac Burkhalter (2020) from C. Baritaud, 2020).

The social relationships between the actors in Figure 3 is complex and intricately interconnected. Drivers are dependent on roadway maintenance to ensure their safety; however, drivers can also be viewed as taxpayers, and increasing infrastructure funding directly and indirectly affects their taxes and allocation of tax funds to other resources. Policy makers, on the other hand are driven both by voters' interests as well as budget considerations. The operation of enforcement agencies is determined by the decisions of legislators, and their operation directly affects U.S. residents, including drivers, voters, and taxpayers. In addition, there is an added complication in the hierarchy of federal versus state legislators and enforcement agencies. The relationships between these actors are visually depicted in Figure 4. It is hoped that by understanding the nuances of these relationships through the framework of ANT, the reason behind the conflicts of interest will be brought to light.

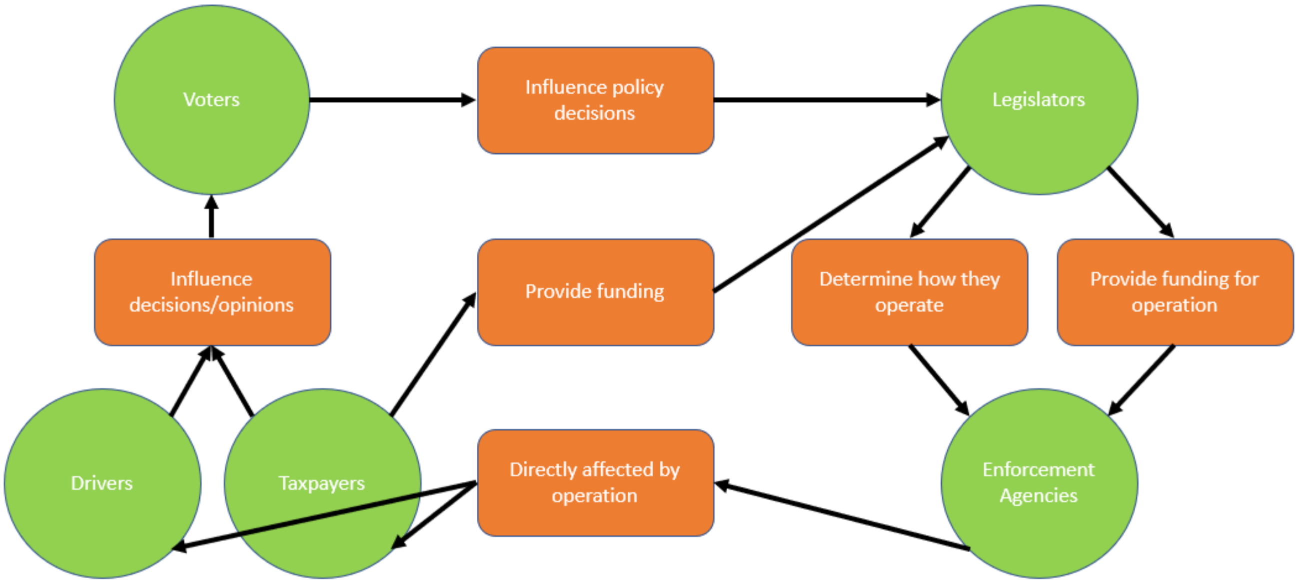

Figure 4: Social Relationships Between Actors in the Roadway Maintenance System. This figure shows the social relationships between some of the important actors in roadway maintenance through an Actor-Network Theory framework. (Created by Isaac Burkhalter, 2020).

In recent years, transportation focus has begun shifting from expanding roadway infrastructures to preserving and maintaining them. With this trend, numerous solutions to the issue have been proposed by different agencies to solve the issues with of roadway maintenance. The US DOT, FHA (2012) suggests using a system of performance targets and budgets at the state, regional, and station levels for quality assurance, as well as prioritizing engineering judgement and system knowledge in decision making. The agency also suggests transitioning from historically used incremental budgeting to "zero-based" budgeting. Policy makers are making strides as well. In the Safe, Accountable, Flexible, Efficient Transportation Equity Act, Congress authorized and funded research into long-term bridge performance, innovative bridge delivery, high performance materials, nondestructive inspection technology, and seismic research in order to develop potential solutions

(Gee & Henderson, 2007). The American Road and Transportation Builders Association suggests a paradigm shift in the focus of the US' transportation system by enabling infrastructure design and maintenance to be more forgiving of human error and shifting efforts from reducing the number of crashes to reducing the severity of crashes (US GPO, 2019, pp. 127-128). It is hoped that analyzing conflicts of interest through ANT will additionally enable the evaluation of the efficacy and feasibility of these proposed solutions.

The end goal of the STS project is to understand the reasons behind conflicts of interest between policy makers and the general public, as it pertains to the U.S. roadway maintenance system. Actor-Network Theory will be used to frame the social relationships between the actors. It is hoped that through this a better understanding will be achieved that will enable the evaluation of various proposed solutions aiming to improve U.S. roadway infrastructure.

WORKS CITED

Alhasan, A., Nlenanya, I., Smadi, O.G., & MacKenzie, C.A. (2018, June 13). Impact of pavement surface condition on roadway departure crash risk in Iowa. *Infrastructures, 3,* 14-29. doi: https://doi.org/10.3390/infrastructures3020014

Baritaud, C. (2020). *Actor-Network Theory (ANT) applied to the Cap Eole wind project* [Lecture notes]. Retrieved from https://collab.its.virginia.edu/access/content/group/46d98863-9e43-4d1f-bd5d-7485d3822e29/Class%20Outlines/Class%20outline%2010-6.pdf

Gee, K.W., & Henderson, G. (2007, October 23). *Highway bridge inspections*. Hearing before the Committee on Transportation and Infrastructure Subcommittee on Highways and Transit, United States House of Representatives. Retrieved from https://www.transportation.gov/testimony/highway-bridge-inspections

Learning Theories. (n.d.). *Actor-Network Theory (ANT).* Retrieved from https://www.learning-theories.com/actor-network-theory-ant.html

McGuire, S. (2020, May 29). *An analysis of modern bridge inspection technologies*. Retrieved from Giatec Scientific website: https://www.giatecscientific.com/education/bridge-inspection-technologies/

Preston, B. (2020, January 23). As states add money to fix roads, U.S. is urged to ante up. *New York Times*. Retrieved from https://www.nytimes.com/2020/01/23/business/us-roadinfrastructure.html

U.S. Department of Transportation, Federal Highway Administration. (2012). *Managing and maintaining roadway assets: the Utah journey* (Report No. FHWA-HIF-12-016). Retrieved from https://rosap.ntl.bts.gov/view/dot/41387/dot_41387_DS1.pdf

U.S. Government Publishing Office. (2019, April 9). *Every life counts: improving the safety of our nation's roadways*. Hearing before the Committee on Transportation and Infrastructure Subcommittee on Highways and Transit, United States House of Representatives. Retrieved from https://www.govinfo.gov/content/pkg/CHRG-116hhrg36978/pdf/CHRG-116hhrg36978.pdf

Vaghefi, K., Oats, R.C., Harris, D.K., Ahlborn, T.M., Brooks, C.N., Endsley, K.A., … Dobson, R. (2012). Evaluation of commercially available remote sensors for highway bridge condition assessment. *Journal of Bridge Engineering, 17,* 886-895. doi: 10.1061/(ASCE)BE.1943-5592.0000303.

Vary, A. (2009). *Nondestructive evaluation technique guide*. Washington, D.C.: National Aeronautics and Space Administration.

Vezner, T. (2007, August 20). I-35 bridge collapse – 13th, final victim recovered. *Saint Paul Pioneer Press*. Retrieved from https://www.twincities.com/2007/08/20/i-35w-bridge-collapse-13th-final-victim-recovered/

Virginia Department of Transportation. (2019). *Maintenance and Operations Comprehensive Review – 2019*. Retrieved from https://www.virginiadot.org/projects/resources/legstudies/Maintenance_and_Operations_Comprehensive_Review_%E2%80%93_2019.pdf

APPENDIX A

			Rating Based, in Part, on Theoretical Sensitivity for Measurement Technologies											
Location	Challenges	Indicator	GPR	Spectra	3D Photo-grammetry	EO Airborne/ Satellite Imagery	Optical Inter-ferometry	LiDAR	Thermal IR	Acoustics	DIC	Radar (Backscatter/ Speckle)	InSAR	Streetview-Style Photography
Deck Surface	Expansion Joint	Torn/Missing Seal	0	8	14	12	11	13	11	0	0	9	0	13
		Armored Plated Damage	0	0	14	12	11	13	11	0	0	0	0	13
		Cracks within 2 Feet	0	8	14	0	12	12	11	0	0	9	0	13
		Spalls within 2 Feet	0	8	14	12	12	12	11	0	0	9	0	13
		Chemical Leaching on Bottom	0	11	0	0	0	0	0	0	0	0	0	0
	Map Cracking	Surface Cracks	0	8	14	12	12	12	11	8	0	9	0	13
	Scaling	Depression in Surface	0	8	14	12	12	12	11	0	0	9	0	13
	Spalling	Depression with Parallel Fracture	0	8	14	12	12	12	11	0	0	9	0	13
Deck Subsurface	Expansion Joint	Material in Joint	0	0	0	0	11	0	0	0	0	0	0	0
	Delamination	Moisture in Cracks	11	0	0	0	0	0	11	0	0	0	0	0
		Internal Horizontal Crack	0	0	0	0	0	0	11	8	0	0	0	0
		Hollow Sound	0	0	0	0	0	0	0	8	0	0	0	0
		Fracture Planes / Open Spaces	12	0	0	0	0	0	0	8	0	12	0	0
	Scaling	Depression in Surface	12	0	0	0	0	0	11	0	0	0	0	0
	Spalling	Depression with Parallel Fracture	12	0	0	0	0	0	11	0	0	0	0	0
	Corrosion	Corrosion Rate (Resistivity)	0	0	0	0	0	0	0	0	0	0	0	0
		Change in Cross-Sectional Area	13	0	0	0	0	0	0	8	0	13	0	0
	Choride Ingress	Choride Content through the Depth	12	0	0	0	0	0	0	0	0	12	0	0
Girder Surface	Steel Structural Cracking	Surface Cracks	0	8	11	0	12	0	11	0	0	0	0	0
	Concr. Structural Cracking	Surface Cracks	0	8	11	0	12	0	11	8	0	0	0	0
	Steel Section Loss	Change in Cross-Sectional Area	0	0	11	12	0	13	11	0	0	11	0	0
	Paint	Paint Condition	0	9	0	0	0	0	11	0	0	0	0	0
	Concrete Section Loss	Change in Cross-Sectional Area	0	0	11	12	0	13	11	7	0	11	0	0
Girder Subsurface	Concr. Structural Cracking	Internal Cracks (e.g. Box Beam)	0	0	0	0	0	0	11	8	0	0	0	0
	Concrete Section Loss	Change in Cross-Sectional Area	0	0	0	0	0	0	0	7	0	11	0	0
	Prestress Strand Breakage	Change in Cross-Sectional Area	9	0	0	0	0	0	0	8	0	9	0	0
	Corrosion	Corrosion Rate (Resistivity)	0	0	0	0	0	0	0	0	0	0	0	0
		Change in Cross-Sectional Area	8	0	0	0	0	0	0	8	0	13	0	0
	Choride Ingress	Choride Content through the Depth	10	0	0	0	0	0	0	0	0	11	0	0
Global Metrics	Bridge Length	Change in Bridge Length	0	0	15	13	0	0	0	0	9	0	12	0
	Bridge Settlement	Vertical Movement of Bridge	0	0	12	0	0	12	0	0	9	0	12	0
	Bridge Movement	Transverse Directions	0	0	12	0	0	12	0	0	9	0	12	0
	Surface Roughness	Surface Roughness	0	9	14	13	12	12	0	0	0	11	13	13
	Vibration	Vibration	0	0	0	0	12	0	0	0	10	12	12	0

Figure A1: Performance Ratings of Commercially Available Sensors. This figure shows performance ratings of commercially available sensors when used for various remote-sensing purposes. (Vaghefi et al., 2012).