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A Mixed Method Study of Infrastructure Resilience Education and Instruction

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A MIXED METHOD STUDY OF INFRASTRUCTURE RESILIENCE EDUCATION AND INSTRUCTION

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Abstract
As the frequency and severity of natural and man-made disasters increases, the importance of improving the resilience of complex infrastructure systems in an uncertain environment is increasingly critical. Proper training and education are key components to addressing this issue, but it is unclear how and where modeling under uncertainty, infrastructure systems management, and resilient systems are integrated into the standard undergraduate and graduate engineering management curriculum. This research uses a mixed method to determine whether and at what level engineering managers receive instruction regarding the implementation of tools and techniques to improve infrastructure resilience. A review of current courses and content informs a systems-thinking approach to resilience and investigates how the topic of infrastructure resilience is being taught. The results of the study identify gaps in existing engineering management curriculum with respect to the topic of resilience. The findings from these results can be used to by the engineering management educator to provide coursework and training that can be used to lead teams that design, build, analyze the resiliency of current infrastructure systems, or restore damaged infrastructure systems to their original state.

Keywords
Infrastructure, resilience, education

Introduction
Critical infrastructure systems such as hospitals, transportation networks, and utility systems, are becoming increasing more complex and interdependent while at the same time there has been a significant increase in operational uncertainty of these systems due to either natural or man-made disasters. Infrastructure resilience is the concept that addresses this uncertainty though it has been defined in many ways by a host of experts across a vast cross-section of disciplines. This research utilized its previous work on an integrative literature review to define resiliency as "an ability to prepare for, withstand, and/or recover from adversity, emergencies or failures in a timely manner and still be able to function at least nominally while minimizing potential losses in the system" (Wilt, Long, & Shoberg, 2016).

Due to the complexity of these infrastructure systems and the various engineering and other disciplines involved with the design and operation of a complex infrastructure system, solutions to improve infrastructure resilience require a multidisciplinary approach and makes the application of operational concepts of engineering management towards understanding and improving infrastructure resilience more important to maintaining, restoring, and adapting critical infrastructure to deal with disasters. It has been argued that engineering management programs provide the leaders needed to manage these complex and interdisciplinary efforts (Perry, Hunter, Currall, & Frauenheim, 2017), so proper training and education of engineering managers in infrastructure resilience is critical to enable them to successfully lead infrastructure resilience programs and projects. However, at this time, it is unclear how and where modeling under uncertainty, infrastructure systems management, and resilient systems are integrated into the standard engineering curriculum.

This research uses a mixed method approach to determine whether and at what level engineering managers receive instruction regarding the implementation of tools and techniques to improve infrastructure resilience. The mixed methods research utilized a qualitative search of current courses in select schools with accredited engineering management programs, either by the American Society for Engineering Management (ASEM) or the Accreditation

Board for Engineering and Technology (ABET), for terms related to infrastructure resilience in addition to content across engineering disciplines and their connection to current studies on engineering pedagogy to inform a systems-thinking approach to resilience and how the topic of infrastructure resilience is being taught. The results of the search were then quantitively investigated to identify trends and gaps in existing engineering management curriculum with respect to the topic of resilience. The findings from these results can be used to by the engineering management educator to provide coursework and training that can be used to lead teams that design, build, analyze the resiliency of current infrastructure systems, or restore damaged infrastructure systems to their original state.

Literature Review:

This study began with seeking to identify a working definition for resilience that could be applied to infrastructure systems. The search began with the two cornerstone documents published by the American Society for Engineering Management; A Guide to the Engineering Management Body of Knowledge and the Engineering Management Handbook (ASEM, 2019). It turns out that neither of these documents have any mention of infrastructure resilience, which indicates there is a gap and opportunity to incorporate concepts of and methods for addressing infrastructure resilience in the Engineering Management Body of Knowledge.

Previous work to determine a working definition for infrastructure resilience through a State-of-the-Art Matrix (SAM) analysis of resilience literature found that resilience is defined somewhat loosely and varies across disciplines and concluded that an appropriate working definition of resilience is "the is an ability to prepare for, withstand, and/or recover from adversity, emergencies or failures in a timely manner and still be able to function at least nominally while minimizing potential losses in the system". (Wilt, Long, & Shoberg, 2016). This definition informed the research of courses in the targeted programs that included related themes or topics.

Since the Department of Homeland Security (DHS) is the agency given the responsibility for infrastructure planning and projection at the Federal level, it is instructive to investigate what efforts they have put forth towards educational initiatives in infrastructure resilience. Ramirez and Rioux conducted a survey of select DHS personnel to identify potential courses and topics to be included in Homeland Security programs to help inform those involved in curriculum development, and their assessment indicates that there is a significant gap and a strong need to include courses into curricula that address response to and mitigation of disasters (Ramirez & Rioux, 2012).

This infrastructure resilience gap was also identified at the highest levels of our national government and addressed with the White House Educators Commitment on Resilient Design, signed in 2016 that calls for a focus on resilient design across all disciplines. Eighty-three schools and fourteen research centers, institutes and associations signed the commitment, to include several of these schools were studied in this research based on their accreditation with either ABET or ASEM. The intent of this commitment is for institutions to commit to teach students who can lead the various activities (such as planning, design, engineering, and construction) to build resilient infrastructure (White House, 2016). This commitment is in line with the goals of this research to identify where and how infrastructure resilience is being taught at institutions of higher education.

Though not an exhaustive search, another avenue pursued was to conduct a search for infrastructure resilience related articles in the American Society for Engineering Education (ASEE) annual conference proceedings over the past 10 years. ASEE is the largest annual gathering of engineering educators in the country and an investigation of the types of articles and divisions in which they appear were used to identify the closest to "real time" state-of-the-art educational research as well as trends in infrastructure resilience education. The search, which incorporated the keywords of either infrastructure, resilience or both, yielded a total of 244 results. There was a significant jump from 19 articles in the 2015 proceedings to over 30 each of the past three years. The division with the largest number of articles was the Civil Engineering Division followed by the Multidisciplinary Engineering Division. The Engineering Management had three articles over the period covered by the search. The search results are shown in Exhibit 1.

Exhibit 1. Infrastructure and/or Resilience Articles in ASEE Conference Proceeding 1998-2018.

Results by Year			Results by Division	
2018	34		Civil Engineering	44
2017	51		Multidisciplinary Engineering	12
2016	41		Community Engagement Division	11
2015	19		Environmental Engineering	9
2014	17		Liberal Education/Engineering & Society	8
2013	17		Minorities in Engineering	8
2012	16		Electrical and Computer	6

2011	12		Construction	5
2010	10		Cooperative & Experiential Education	5
2009	2		Energy Conversion and Conservation	5
2008	3		Entrepreneurship & Engineering Innovation	5
2007	7		International	5
2005	5		K-12 & Pre-College Engineering	5
2004	4		Design in Engineering Education	4
2003	2		First-Year Programs	4
2002	2		Mechanics	4
2001	1		College Industry Partnerships	3
1998	1		Computing & Information Technology	3
			Educational Research and Methods	3
			Engineering Management	3
			Systems Engineering	3
			Architectural	2
			Computing and Information Technology	2
			Graduate Studies	2
			Information Systems	2
			Military and Veterans	2
			Military and Veterans Constituent Committee	2
			Technological and Engineering Literacy/Philosophy of Engineering	2
			Women in Engineering	2
			Aerospace	1
			Architectural Engineering	1
			Division Experimentation & Lab-Oriented Studies	1
			Engineering Economy	1
			Engineering Ethics	1
			Engineering Leadership Development	1
			Engineering Leadership Development Division	1
			Industrial Engineering	1
			Instrumentation	1
			Liberal Education	1
			Manufacturing	1
			National Science Foundation	1
			Pre-College Engineering Education	1
			Pre-College Engineering Education Division	1
			Two Year College Division	1

Findings from the review of current literature are that there is a significant gap in addressing infrastructure resilience in both the formal engineering management body of knowledge and engineering management educational research perspectives. This study aims to address overall trends in infrastructure resilience to help close that gap.

Multidisciplinary Pedagogy:

Due to the wide range of systems and disciplines involved in infrastructure resilience, effective educational efforts should be multi- or inter-disciplinary. Stember provides a good elaboration of the distinctions between the two approaches. Multidisciplinary involves several disciplines who each provide a different perspective on a problem or issues. The student is required to integrate the often-diverse ideas. Interdisciplinary: integration of the contributions of several disciplines to a problem or issue is required. Interdisciplinary integration brings interdependent parts of knowledge into harmonious relations through strategies such as relating part and whole or the particular and the general. A genuinely interdisciplinary enterprise is one that requires more or less integration and even modification of the disciplinary contributions while the inquiry or teaching is proceeding and is a complex endeavor to explicate relationships, processes, values, and context using the diversity and unity possible only through collaborative

approaches. (Stember, 1991). This study incorporated a multidisciplinary approach to its search for infrastructure resilience courses and research areas.

Methodology:

The research started with an online search conducted for infrastructure resilience education that yielded over 39 million website hits. The search was refined by searching only for "infrastructure resilience education", but still yielded about 575 website hits, many of which were not related to this investigation. This is due to the various ways that resilience, infrastructure, and education are defined and used in practice. To narrow the study down and make it more pertinent to undergraduate and graduate level education, this study focused on two groups of universities. The first group of institutions considered were the seven institutions with graduate Engineering Management programs certified by the American Society for Engineering Management (ASEM, 2019). This initial group was expanded to include the sixteen schools with Accreditation Board of Engineering and Technology (ABET) accredited Engineering Management programs (ABET, 2019). One school, the Missouri University of Science and Technology, fit both criteria.

This sample was selected to filter out the various types of engineering management programs since engineering management can be loosely interpreted and housed in various departments or programs (such as a business school, industrial engineering department, etc.). This list was not designed to be all inclusive, but rather a cross section of schools that have been accredited in order to provide a look at a broad range of programs and institutions that are well regarded in the field and have met common criteria. This also narrowed down the programs to an appropriate number from which to build the framework of this study which can be utilized as the scope is increased in future work. Additionally, information on infrastructure resilience related courses was not found for all schools, so the final list of schools studied was reduced to fifteen, as shown in Exhibit 2.

Exhibit 2. List of ASEM and ABET Accredited Engineering Management Programs.

Institution		**Category**
1	Missouri University of Science and Technology	ASEM Accredited & ABET EM Accredited
2	Drexel University	ASEM Accredited
3	Old Dominion	ASEM Accredited
4	University of Idaho	ASEM Accredited
5	Western Michigan University	ASEM Accredited
6	Air Force Institute of Technology	ABET EM Accredited
7	Arizona State University *	ABET EM Accredited
8	Clarkson University *	ABET EM Accredited
9	Gonzaga University	ABET EM Accredited
10	Montana State University	ABET EM Accredited
11	North Dakota State University	ABET EM Accredited
12	Rensalear Polytechnic Institute *	ABET EM Accredited
13	Stevens Institute of Technology *	ABET EM Accredited
14	United States Military Academy	ABET EM Accredited
15	University of Connecticut	ABET EM Accredited
Not included due to lack of data		**Category**
1	The British University in Dubai	ASEM Accredited
2	St. Cloud State	ASEM Accredited
3	California State University, Northridge	ABET EM Accredited
4	South Dakota School of Mines and Technology	ABET EM Accredited
5	Universidad Ana G. Mendez - Gurabo Campus	ABET EM Accredited
6	University of Arizona	ABET EM Accredited
7	University of the Pacific	ABET EM Accredited

* Signatory Institution to the White House Educators Commitment on Resilient Design

The evaluation of each program followed the methodology of Klassen, Reeve, Rottmann, Sacks, Simpson, and Huyuh who assessed how engineering leadership programs bin together along various dimensions – end goal, application of leadership learning, scale of leadership action, leadership emphasis, participant selection, compulsoriness, and integration (Klassen, Reeve, Rottmann, Sacks, Simpson, & Huyuah, 2016). The qualitative evaluation of these Engineering Management programs sought to identify key dimensions and develop a conceptual framework based on the pedagogical research that applied to the institutions studied. This strategy employed a modified version of analytical induction (Patton, 2014).

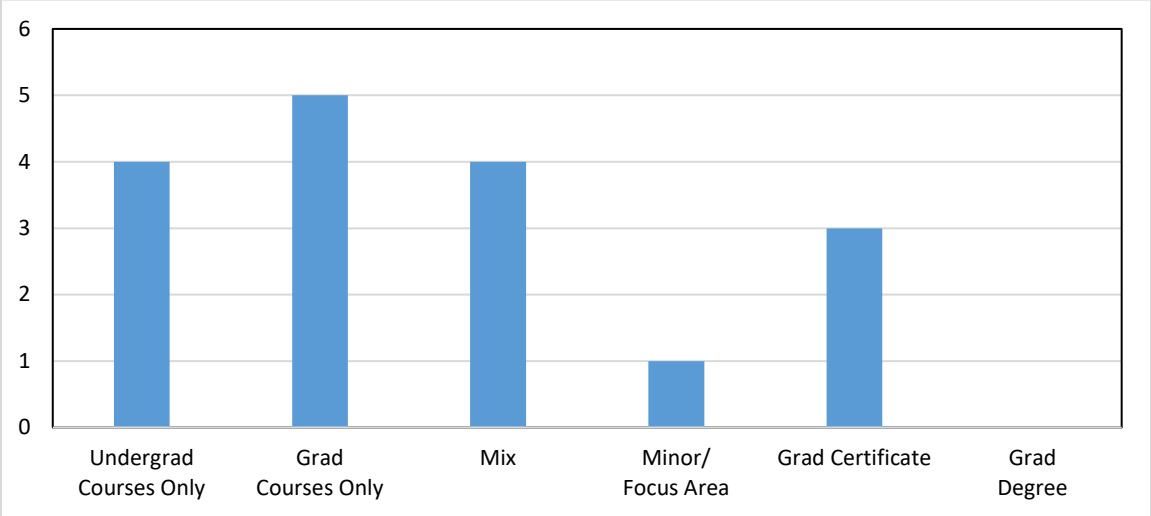
The search began in the course catalog for each institution's engineering management program for the keywords "infrastructure" and "resilience" other related terms. Then the search was expanded for any course in the institution's catalog with these keywords. Finally, the search expanded to research centers and faculty. The results from the search from each institution were captured and cataloged according to institution, program, individual course number and description, graduate or undergraduate, course focus, and whether the courses were cross listed or included other departments to indicate multidisciplinary.

From the search of each school's website and course catalog for courses and reach related to infrastructure resilience, five dimensions emerged to assess the programs emerged. The schools were assessed on: Program Structure, Academic Focus, Research Center/Focus Area, Multidisciplinary, and Disciplinary Programs. By conducting a qualitative analysis of the program and course descriptions focused on keywords linked to infrastructure resilience, a quantitative assessment of the types and numbers of programs reveals the state-of-the art of current infrastructure resilience education at these selected schools. An in-depth discussion on each dimension follows.

Dimension 1: Program Structure

The structure of each program fell into one of the following categories: undergraduate courses only, graduate courses only, or a mix of undergraduate and graduate courses. Some programs also afforded the opportunity to earn either an infrastructure resilience related minor/focus area or graduate certificate. No programs offered a purely infrastructure resilience related graduate degree (Master or PhD). The breakdown across these categories are shown in Exhibit 3.

Exhibit 3. Dimension 1: Program Structure.

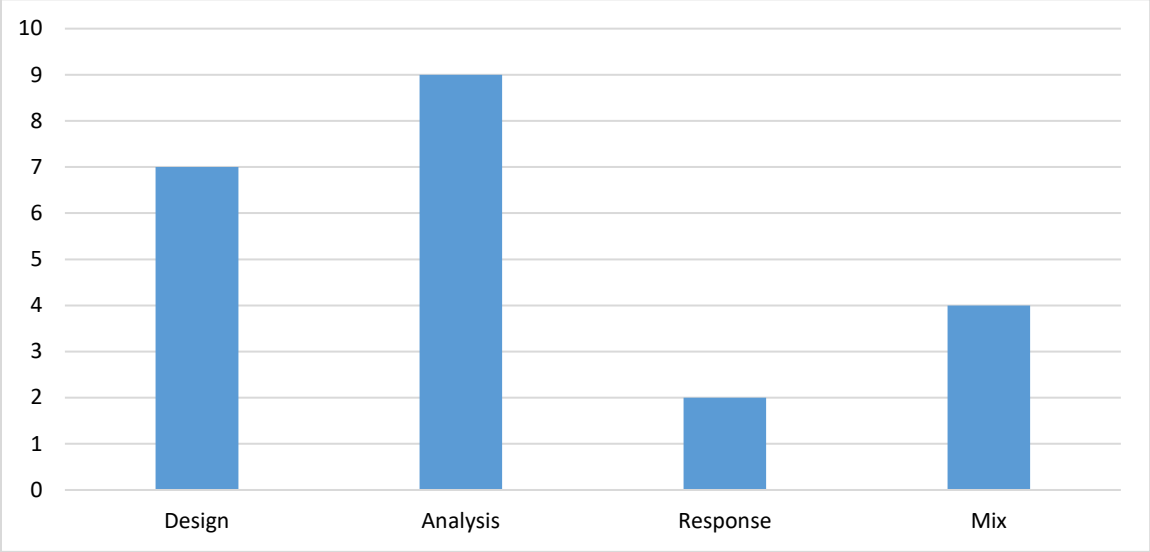


Dimension 2: Academic Focus

Assessing the program and course descriptions for each institution identified whether the program/courses focused more on design for resilience, assessment of as-built environment, or disaster response. The determination the breakdown of the courses focused on if the course descriptions described designing infrastructure to be resilience, how to assess current infrastructure for resiliency, how to restore infrastructure/disaster response. Several of the programs incorporated a mix of these three focus areas. The breakdown across these categories are shown in Exhibit 4. The majority of programs focus on assessment of the as-built environment for resilience with a slightly smaller number of programs focused on incorporating resilience into design. Only two programs taught response concepts.

About a third of the programs incorporated a mix of the three areas, with two those programs incorporating all three areas.

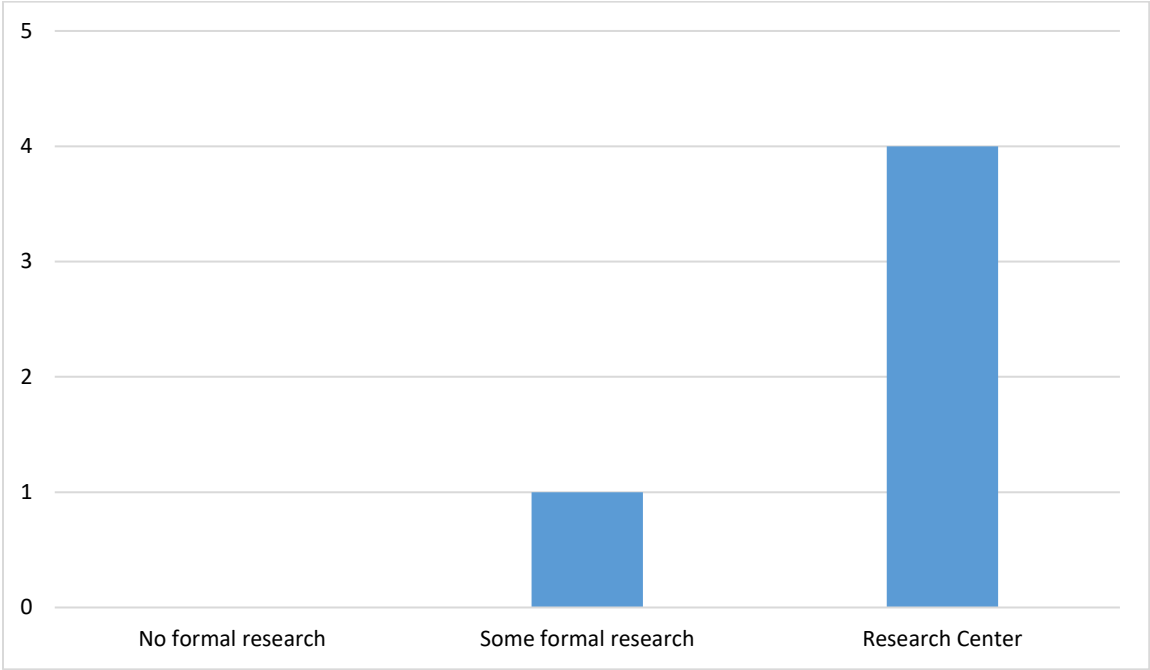
Exhibit 4. Dimension 2: Academic Focus.



Dimension 3: Research Center/Focus Area

The program descriptions and instructor biographies identified if the institution had a specific center that conducted research into infrastructure resilience or if it is a faculty area of research. Housing of a research center or the indication that infrastructure resilience is a research topic of the faculty typically provides opportunities for this research to enter into the classroom or student research opportunities, thereby enhancing educational engagement with infrastructure resilience topics. The breakdown in shown in Exhibit 5.

Exhibit 5. Dimension 3: Research Center or Research Focus Area.

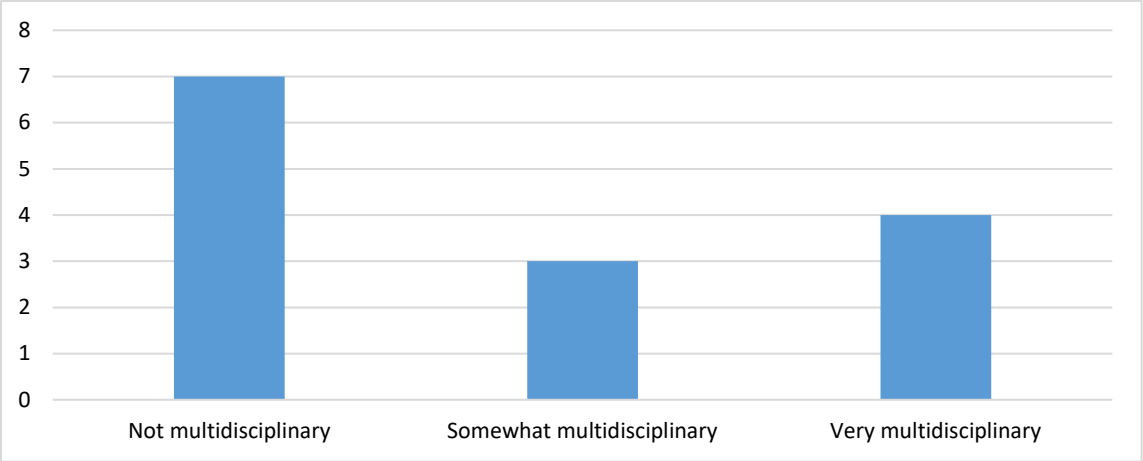


Dimension 4: Multidisciplinary

The level of multidisciplinary work was assessed for each program by looking at several elements to include if the course was cross-listed with multiple departments, the number and types of departments listed in the program or course descriptions, and the number and types of departments included in research descriptions. A slight majority of programs are multidisciplinary, but a large number do not appear to incorporate multidisciplinary education into their teaching of infrastructure resilience topics. The rankings were based on the following rubric:

Not multidisciplinary: only one department listed in program, course, or research material
Somewhat multidisciplinary: only one additional department listed in program, course, or research material
Very multidisciplinary: more than one additional department listed in program, course, or research material

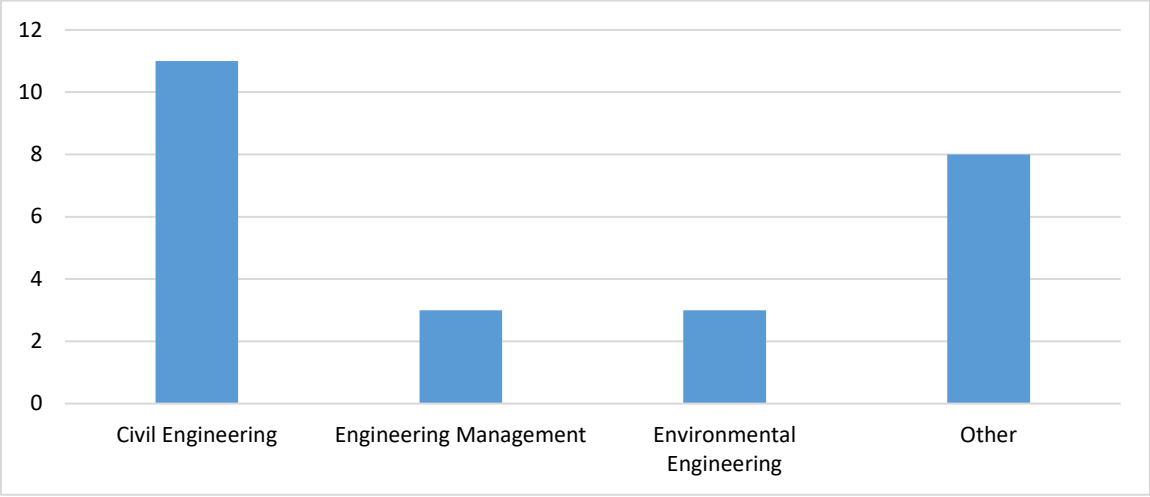
Exhibit 6. Dimension 4: Multidisciplinary.



Dimension 5: Disciplinary Departments

Related to the investigation of the programs relative level of multidisciplinary connectedness, the types of disciplinary departments involved in infrastructure resilience was captured. As shown in Exhibit 7, the majority of programs house their infrastructure resilience education capacity in their civil engineering program, with environmental engineering and engineering management. Departments in the other category include architectural engineering, construction management, industrial and systems engineering, and homeland security.

Exhibit 7. Dimension 5: Disciplinary Departments



Discussion

The significant weather events of the Spring of 2019 (unprecedented numbers of tornados and historic flooding along some of our nation's major waterways), demonstrate the need and timeliness of this research into where and how infrastructure resilience is being incorporated into engineering management education. Engineering managers are uniquely postured, based on the nature of the discipline, to lead the design, analysis and response to improving the resilience of complex and multidisciplinary infrastructure systems. But the study of where and how infrastructure resilience is being incorporated within these fifteen institutions with engineering management programs is very instructive as to the gaps in the current state of infrastructure resilience education.

Through the qualitative investigation of the 15 programs selected for this study, five dimensions emerged from which to quantify the number of programs in each portion of the spectrum under each specific dimension. This quantitative assessment helps identify the trends and gaps in current infrastructure resilience education.

There is a significant lack of discussion on the instruction of infrastructure resilience education within the engineering management education discipline. Less than 2% (3 of 244) papers presented at the ASEE Annual Conference over the past ten years tied to infrastructure resilience education were tied to the Engineering Management Division.

The breakdown across programs teaching at the undergraduate, graduate, or a mix of both is evenly distributed. This is greatly impacted by whether the school has an undergraduate or graduate program. More enlightening though is where the institution has a research center or research focus from their faculty on infrastructure resilience. Only one third of the institutions in the study incorporate infrastructure resilience research, whether in the form of a research center or a faculty research focus area.

Finally, the most significant gap is in the incorporation of a multidisciplinary approach to infrastructure resilience education. Almost half (7 of 15) of the institutions did not describe a multidisciplinary approach to infrastructure education. And the clear majority (11 of 15) of the programs connected infrastructure education to the civil engineering program. While the largest component of an infrastructure system is typically the structural, and hence, civil engineering component, infrastructure systems are increasingly complex and multidisciplined when the electrical, mechanical, information technology, environmental, and safety/security components are incorporated. Only 20% (3 of 15) programs had a connection to engineering management courses displays the gap due to the lack of connection to engineering management programs. Due to the nature of the engineering management discipline as teaching engineers how to design, build, analyze, and restore across a multitude of disciplines, there is great opportunity to demonstrate the value and applicability of engineering management programs as multidisciplinary.

In summary, the teaching of infrastructure resilience tends to be siloed into graduate civil engineering programs and not strongly linked to faculty and/or research centers. The academic focus of the programs is relatively evenly split between design of new infrastructure systems and analysis of the as-built or to be built environment. There are a few institutions that are focused on the mix of design, analysis, and disaster response for infrastructure resilience, incorporating a multidisciplinary approach, and integrating research into classroom instruction. There appears to be a large gap, and therefore a great opportunity, for engineering management programs to expand their instruction in infrastructure resilience topics. The lessons learned from this study can inform institutions that are looking to broaden their incorporation of infrastructure resilience into their academic program as to best practices linked to pedagogy.

Recommendations and Potential Areas for Future Research:

The major recommendation is that academic institutions with engineering management programs at either the undergraduate and/or graduate level use this framework with which to evaluate how their program addresses the instruction of infrastructure resilience. Specifically, they can assess if they have coursework in these topic areas, if there is multidisciplinary approach, and if faculty research is being connected to classroom instruction. They can then look to the best practices from other institutions identified in this study to fill in the gaps in their programs.

The most robust programs studied incorporated a research center and/or faculty research with an online certificate or graduate program that included several classes in infrastructure resilience that incorporated all three focus areas: design for resilience, assessment of the as-built environment, and disaster response. This can serve as a model for programs seeking to be at the leading edge of meeting the increasing demand for engineer managers that can lead and solve these complex infrastructure resilience issues.

A second recommendation is to expand this study to non-ASEM and non-ABET accredited institutions. There are many more engineering management programs across the country that can be investigated to determine what other best practices are available to incorporate across the field to improve the overall instruction of infrastructure resilience topics.

Additionally, academic institutions are not the only entities operating in the infrastructure resilience education realm. Several societies, Federal agencies, cooperative programs, and conferences are offering professional education courses or programs in infrastructure resilience. These include the American Society for Civil Engineering (ASCE) (American Society of Civil Engineers, 2019), the Center for Infrastructure Transformation and Education (CIT-E), a community of practice comprised of faculty members who share a passion for infrastructure education and intends to transform the way that civil and environmental engineering topics are taught, (Center for Infrastructure Transformation and Education, 2019) the George Mason University Center for Infrastructure Protection & Homeland Security which is currently completing a multi-year Higher Education Initiative with DHS to develop and evaluate curriculum for graduate and professional workforce training and education in topics vital to the critical infrastructure community (Center for Infrastructure Protection and Homeland Security, 2019), and the Critical Infrastructure Resilience Institute, which conducts research and education that enhances the resiliency of the nation's critical infrastructures and the businesses and public entities that own and operate those assets and systems (Critical Infrastructure Resilience Institute, 2019).

Finally, the investigation can be further expanded to survey practicing engineering managers in the field of infrastructure resilience to identify the education gaps they feel should be filled to assist them in their work. Expanding the research in these areas will not only provide a larger menu of best practices from which programs can incorporate infrastructure resilience, but also provide a more holistic look at infrastructure education as a whole to identify system gaps and opportunities for improvement across the spectrum of engineering education; undergraduate, graduate, and professional.

References:

Accreditation Board for Engineering and Technology. (2019). *ABET-Accredited Programs*. Retrieved from Accreditation Board for Engineering and Technology: http://main.abet.org/aps/Accreditedprogramsearch.aspx

American Society for Engineering Management. (2019). *Graduate Program Certification*. Retrieved from American Society for Engineering Management: https://asem.org/Graduate-Program-Cert

American Society of Civil Engineers. (2019). *Infrastructure*. Retrieved from American Society of Civil Engineers https://www.asce.org/infrastructure/

Center for Infrastructure Protection and Homeland Security. (2019). Retrieved from Center for Infrastructure Protection and Homeland Security: https://cip.gmu.edu/

Center for Infrastructure Transformation and Education. (2019). Retrieved from Center for Infrastructure Protection and Homeland Security: http://www.cit-e.org/

Critical Infrastructure Resilience Institute. (2019). Retrieved from Critical Infrastructure Resilience Institute: http://ciri.illinois.edu/

Department of Homeland Security. (2013). *NIPP 2013: Partnering for Critical Infrastructure and Resilience*. Retrieved from Department of Homeland Security: https://www.dhs.gov/sites/default/files/publications/NIPP%202013_Partnering%20for%20Critical%20Infrastructure%20Security%20and%20Resilience_508_0.pdf

Klassen, M., Reeve, D., Rottmann, C., Sacks, R., Simpson, A., & Huyuh, A. (2016). Charting the Landscape of Engineering Leadership Education in North American Universities. *Proceedings of the 123rd American Society for Engineering Education Annual Conference,* (CD-ROM).

Patton, M. (2014). *Qualitative Research & Evaluation Methods, Fourth Edition*. SAGE Publications.

Perry, S., Hunter, E., Currall, S., & Frauenheim, E. (2017). Developing Engineering Leaders: An Organized Innovation Approach to Engineering Education, *Engineering Management Journal*, *29(2)*, 99-107.

Ramirez, C., & Rioux, G. (2012). Advancing Curricula Development for Homeland Security Education through a Survey of DHS Personnel. *Journal of Homeland Security, 1(1),* 6 – 25.

Stember, M. (1991). Advancing the Social Sciences Through the Interdisciplinary Enterprise. *The Social Science Journal, 28(1)*. 1-14.

White House. (2016). *Designing for a Resilient Future.* Retrieved from The White House: https://obamawhitehouse.archives.gov/blog/2016/10/31/designing-resilient-future

Wilt, B., Long, S., & Shoberg, T. (2016). Defining Resilience: A Preliminary Integrative Literature Review. *Proceedings of the American Society for Engineering Management 2016 International Annual Conference, S. Long, E-H. Ng, C. Downing, & B. Nepal eds*., (CD-ROM).

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