The Emergence of Accelerated Bridge Construction: Analysis of the Components of its Sociotechnical System

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Spring 2020

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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Introduction: The Need to Address the Urgent Infrastructure Problem

In April 2019, President Donald Trump and Democratic congressional leaders came to a verbal agreement to pursue and implement a $2 trillion infrastructure plan to improve the United States' highways, railroads, bridges, and broadband (Karni, Cochrane, & Rappeport, 2019, p. 1). While the infrastructure bill ultimately fell apart and was not signed, the discussion that this bill instigated came at a pivotal time, as it was recently identified by the Federal Department of Transportation in 2016 that out of the approximately 614,000 public road bridges in the US, about 56,000 (just over 9%) were considered structurally deficient (Kirk & Mallet, 2018, p. 2). For a bridge to be deemed structurally deficient, its elements, such as the foundation, piers, or deck slabs, require monitorization and ultimately renovation, but its structure can maintain its daily traffic and will not collapse. In addition, as seen in Figure 1 below, almost four out of every ten (39%) of all bridges in the United States are 50 years or older, the majority of which are only designed to have a lifespan of 50 years (ASCE, 2016, p. 2). In order to address the urgent issue of these structurally deficient bridges in a faster and safer manner than traditional construction, the method of accelerated bridge construction was introduced by Federal Government-run transportation programs.

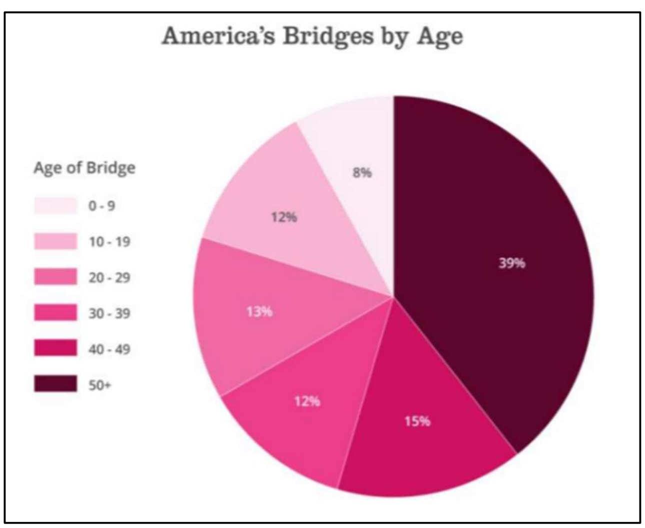

Figure 1: America's Bridges by Age. The majority of the bridges in 2016 are 40 years or older with a design lifespan of 50 years (ASCE, 2016, p. 2).

Accelerated Bridge Construction (ABC) is a method for rapidly replacing bridges using prefabricated elements or systems and then moving them into position, instead of assembling the bridge components on site. This methodology allows for a shorter construction period, which decreases the number of lane closures and detours, in a manner that is safer for pedestrians and laborers, and more cost-effective (Federal Highway Administration, 2019, p. 1). In 2003, the National Cooperative Highway Research Program (NCHRP) published a synthesis report on prefabricated bridge elements and systems (PBES), the concept behind ABC techniques, but the use of traditional bridge construction did not waver (Ralls, 2014, p. 2). Despite Accelerated Bridge Construction first emerging in the 1980's, its implementation in the construction industry has been very gradual. In order to identify how ABC will adapt from this initial discrepancy, I will be applying the framework of Frank W. Geels' "Multi-level Perspective on Sustainability Transitions: Response to Seven Criticisms" to analyze the corresponding socio-technical system and its components.

Part 1: ABC Technology Can Solve the Infrastructure Problem

As referenced earlier, it has become clear that the United States has a vested interest in improving the nation's infrastructure. At the current rate of inspection and repair being done by both public and private entities, the task of fixing the over 56,000 structurally deficient bridges would take approximately 80 years (American Road & Transportation Builders Association, 2019, p. 1). Therefore, it should be clear that Accelerated Bridge Construction has great potential to not only limit future project traffic delays, but to make it far more realistic to repair and genuinely improve the state of our current infrastructure. If the appropriate circumstances for implementation of the ABC methodology could be clarified, the goal of fixing all the structurally deficient bridges in the US would be more attainable.

Since the introduction of Accelerated Bridge Construction in the 1980's, State Departments of Transportation (DOTs) have requested research projects for specific ABC technologies in an effort to "advance nationwide ABC implementation" (Ralls, 2014, p. 2). However, the growth in popularity of ABC methods in the United States did not fluctuate as a result initially. The relationships between state and federal DOTs, the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), construction and engineering industry partners, and academic research institutions may be at the root of this delayed procedural uptake.

In terms of research, several state DOTs, the FHWA, and many academic and industry organizations have sponsored ABC-related research. The Oregon DOT led a pooled-fund project to "develop a decision tool to help determine whether a project is a good candidate for ABC," which is now being used in a number of states (Ralls, 2014, p. 3). Also, the FHWA has completed several years of extensive research on ultra-high performance concrete for its use in prefabricated concrete elements in ABC (Lysett, 2018, p. 1). In 2013, the Research and Innovative Technology Administration, under the U.S. Department of Transportation, funded the establishment and operation of the ABC University Transportation Center (ABCUTC) at Florida International University, along with Iowa State University and the University of Nevada at Reno (Ralls, 2014, p. 7). This research project continues to investigate a variety of sub-fields in ABC, such as pre-cast bridge railing, seismic connection details, and "compiling ABC projects and research into databases for ready access by bridge professionals in their work" to aid industry implementation (Ralls, 2014, p. 4). While it is clear that there is currently a significant effort in academia and government entities to expand our knowledge of Accelerated Bridge Construction, this promising technique has only just now started to be used more commonly.

One possible explanation for this discrepancy may be due to several unlikely but notable catastrophic accidents that have occurred during ABC projects, causing traffic delays, construction delays, and injuries or fatalities. On one specific project at Florida International University, a newly installed pedestrian bridge constructed with ABC techniques collapsed, killing 6 people in March of 2018. Shortly after, the National Safety Transportation Board conducted an investigated into the cause of the collapse, and determined that it originated from a design error that overestimated the capacity and underestimated the expected loads at a point where two truss members were connected to the bridge deck (O'Neil, 2018, p. 1). This pedestrian bridge, which should have been able to withstand a Category 5 hurricane and last 100 years, was supposed to be a representation of the innovative ABC work that has taking place at Florida International University. Instead, following the collapse, a media frenzy took place in which Accelerated Bridge Construction was portrayed in a very negative light.

Alternatively, the reason why Accelerated Bridge Construction is only now gaining momentum in bridge rehabilitation or replacement projects may be due to the Federal Highway Administration's *Every Day Counts* (EDC) initiative established in 2009. The EDC movement is a state-based model used "to identify and rapidly deploy proven but underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce congestion and improve environmental sustainability (Zicko, 2015, p. 1). While ABC is a significant aspect of the innovative implementations of the EDC initiative and the number of ABC projects has gradually increased as a result, the initiative may not have been adequately identifying the appropriate circumstances for these techniques. After three years, in 2012, the EDC reported that only approximately 1,000 bridge projects were built "in an accelerated manner using some form of PBES technology" (Ralls, 2014, p. 6). If the emphasis on utilizing ABC in more bridge construction projects is increased, and initiatives originating from construction and engineering industry partners are implemented, the use of Accelerated Bridge Construction could be more broadly applied, and the state of our nation's infrastructure could be drastically improved.

Ultimately, all of the relevant organizations involved in the research and implementation of Accelerated Bridge Construction have shown that they are capable of being efficient and productive in their own endeavors. As a result of this level of productivity, the balance of government-run and academic programs has resulted in a growing but stable base of resources and knowledge in the research domain. Therefore, determining when and why the emerging technology of Accelerated Bridge Construction is actually implemented in the field is crucial to understanding the socio-technical system's effectiveness in identifying and adapting to influential innovations.

Part 2: Implementing Geels' "Multi-Level Perspective on Sustainability Transitions" Framework

In "Multi-level Perspective on Sustainability Transitions: Response to Seven Criticisms" by Frank W. Geels, he begins by discussing three different systematic changes, or socio-technical transitions, regarding the emergence and corresponding acceptance or rejection of innovative technology. The first aspect of sustainability transitions that Geels mentions is that these changes are "goal-oriented… in the sense of addressing persistent environmental problems," which is indicative of the need for this innovation (Geels, 2011, p. 25). This initial aspect does not discuss the costs and benefits of the implementation of this transition, but rather focuses on the necessity for change in times of environmental shortcomings. Next, Geels states that the second characteristic of sustainable transitions is that “the most sustainable solutions do not offer obvious user benefits” and that it is “unlikely that environmental innovations will be able to replace existing systems without changes in economic frame conditions (e.g., taxes, subsidies, regulatory frameworks)” (Geels, 2011, p. 25). While this point is fairly intuitive, Geels makes the important distinction between what is desired the most and what is realistic in terms of implementation. The third characteristic that Geels mentions refers to “the empirical domains” of the pertinent industry of innovation, which are “characterized by large firms that possess ‘complementary assets’ such as specialized manufacturing capability, experience with large scale test trials, access to distribution channels, service networks, and complementary technologies” (Geels, 2011, p. 25). According to Geels, these three unique aspects can collectively define any innovative, emerging technology.

In the following section, Geels introduces the concept of his multi-level perspective (MLP) that “conceptualizes overall dynamic patterns in socio-technical transitions,” which combines economics, science, and technology. This conceptual framework can be defined by three interrelated aspects: niches, socio-technical regimes, and socio-technical landscapes. The regime level is the primary area of focus, because “transitions are defined as shifts from one regime to another regime” (Geels, 2011, p. 26). The socio-technical regime consists of the structure that provides the “stability of an existing socio-technical system.” On a smaller scale, niches can be considered specific components of a larger innovative technology that combine to form a socio-technical regime. Lastly, socio-technical landscapes can be considered “the wider context, which influences niche and regime dynamics,” from a societal perspective, including “demographical trends, political ideologies, societal values, and macro-economic patterns” (Geels, 2011, p. 27).

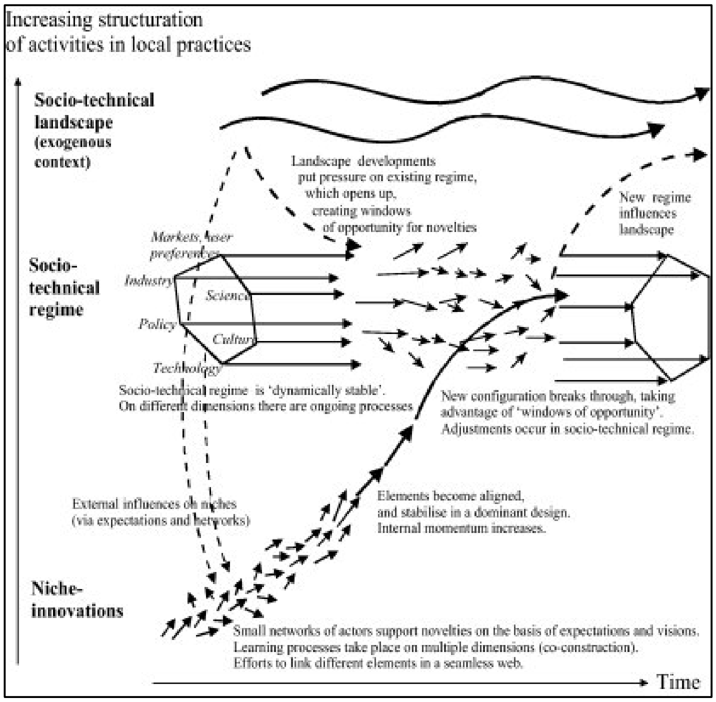

Figure 2: Multi-Level Perspective on Transitions (Geels, 2011, p. 28)

In Figure 2, a visual representation of Geels' multi-level perspective is shown, displaying the necessary sequences of events for either an advancement in a current socio-technical regime to occur or for a new regime to emerge and influence the socio-technical landscape. In order for the "network of actors," or niche-innovations, to accumulate into one of the infinitely possible variations of improvement that can impact the existing regime, expectations from this regime must align the goals of the niche-innovations into a cohesive effort targeted at a specific issue or shortcoming. Although Geels does not expand on how these issues with the existing regime are identified and simply states that the development effort originates from "visions," it will be shown in the following section how this process occurred for Accelerated Bridge Construction technology.

Applying Geels' Framework to the Emergence and Implementation of ABC

While many components of Accelerated Bridge Construction may seem to not directly relate to sustainability concerns, the emergence of this technology has occurred as a result of new demands in the industry. Specifically, ABC technology has filled a void in the construction industry where owners and contractors no longer need to significantly impact the transportation efforts of the people around them. In a sense, while the environmental factors have not received as much research, the new ability to rapidly replace a structurally deficient bridge before any damage to the surrounding areas and especially commuters passing by, is indicative of a goal-oriented sustainability transition in this field.

Geels' multi-level perspective can be directly applied to the emerging technology of Accelerated Bridge Construction. First, niches can be thought of as any significant aspect of this new technology, such as the advanced prefabrication of bridge elements, the complex methods of transportation, the variety of structural placement methods, and many other factors. These niches are innovative elements that have sparked the transition from traditional construction methods to accelerated. Next, the socio-technical regime consists of the interconnected network of public and private organizations involved in the research and implementation of Accelerated Bridge Construction methods. This regime includes the previously mentioned organizations, such as AASHTO, FHWA, state and federal DOTs, academic research institutes, and engineering and construction partners. Lastly, the socio-technical landscape can be thought of as the system as a whole, comprised of all research, implementation, interactions amongst the vast network involved in the ABC technology, and the public's perception. This application of Geel's framework can be visualized in Table 1 below.

Domain	**Relevant ABC Example**
Sociotechnical Niches	Bridge Element Prefabrication, Specialized Transportation Vehicles, or Structural Placement Methods
Sociotechnical Regime	AASHTO, FHWA, state and federal DOTs, academic research institutions, or engineer/construction partners
Sociotechnical Landscape	All research, implementation, intra-network communication, or the public's perception

Table 1: Application of Geel's MLP Framework to Accelerated Bridge Construction

Part 3: Identifying Methods of Future ABC Development

Based on the application of Geels' multi-level perspective to the emerging technology of Accelerated Bridge Construction, several important inferences can be made. First, it is clear that the niche innovations are the driving force behind the transformative implementation of ABC in a relatively stagnant construction industry. Specific niches, such as self-propelled modular transporters (SPMTs), which are platform vehicles capable of transporting large bridge sections, that each solve a unique problem associated with bridge construction, are not only what makes this technology effective, but also require alignment amongst each other to form a dominant design. For example, the niche innovation of prefabricating a concrete bridge deck offsite would not be a relevant factor in this socio-technical landscape if it were not for the interrelated inventions of specialized transportation techniques, such as SPMTs, and structural placement methods to actually transfer these bridge decks from a warehouse onto a superstructure. Therefore, it is quite possible that niche innovations drive the creation of additional innovations to solve emerging problems that come with this new technology.

Next, the socio-technical regime that was previously defined as the collective group of relevant organizations involved in research and implementation can be considered “dynamically stable” due to vast number of factors that influence their connected network of activities. Specifically, according to Geels, these organizations are involved in science, policy, technology, and culture, each in their own unique ways. While science and technology can be clearly associated with the research and development side of Accelerated Bridge Construction, and policy can be thought of as the manner in which ABC is implemented in the construction and engineering industries, it is not as immediately clear from an analytical standpoint how the factor of culture is involved. However, it is evident that many of the negative aspects of traditional bridge construction have been shown to affect various aspects of culture, and as a result it is likely that there is a connection between the motivation behind the emerging technology of ABC and these cultural issues. Therefore, the behavior that this socio-technical regime is responsible for likely originates from systemic cultural difficulties that are experienced in everyday life, specifically from a transportation and infrastructure perspective.

Next, on an even larger scale the ABC socio-technical landscape is forcing change on the existing regime, which has opened up, creating opportunities for specializations. The existing regime, which can be thought of as traditional bridge construction of which we are accustomed to their lengthy delays and arduous affects on traffic, has shifted, and aspects of it have faded away for the benefit of the industry in the future. The evolution of this existing socio-technical regime has originated from societal values that reach beyond the construction industry: the demands for increasingly high levels of efficiency and worker safety. Elements of Accelerated Bridge Construction have come together to satisfy both of these goals, which is indicative of its inevitable future success in implementation. As aspects of construction that have a heavy impact on human safety and efficiency continue to progress technologically, the existing regime of bridge construction will remain dynamic and fluid in nature.

One aspect of the socio-technical landscape, or as Geels put it, "the wider context, which influences niche and regime dynamics," can be thought of as the public perception of Accelerated Bridge Construction, which has been shown to be a fluid concept, based around the behavior of the regime. While ABC research has increased significantly in the past 15 years, the media coverage of this technology is still relatively new in the sense that the majority of the major news outlets do not cover it unless a serious accident occurs. This emphasis on only reporting ABC-related news that will receive the most views and clicks for the news networks, i.e. very rare catastrophic failures, has resulted in some negative press for the technology. For example, following the ABC-constructed pedestrian bridge collapse at Florida International University that killed 6 people, the mainstream media attacked this new influential technology and those that were a part of it. This unexpected negative spotlight on Accelerated Bridge Construction, which was expressed through national news outlets, affected the existing regime dynamics, by spreading a fear of implementation in engineering and commercial contracting firms that are less familiar with the technology.

While it is uncommon for a very specific and technical topic in the construction industry to earn national news network attention in a positive light, there are thousands of journals and articles on Accelerated Bridge Construction from less popular sources. In fact, the public's perception of ABC likely originates from a variety of government sources, such as websites for departments of transportation, and academic research articles published by Universities. It is worth noting, however, that the level of popularity of a news source is not necessarily indicative of its level of accuracy. As a result, despite the rare but misleading attention from major news outlets, the public at least has access to readily available resources that are accurate on the topic. This level of detail available to the public means that despite any unexpected shifts in the socio-technical regime due to new niche-innovations, the corresponding socio-technical landscape will always have a certain level of stability, in the sense that the public will always be able to identify what is true and not true pertaining to the subject.

Conclusion

Upon analyzing the emerging technology of Accelerated Bridge Construction through Geels' multi-level perspective, it is clear that many factors involved in the research and implementation initially went undiscovered. By identifying specific components of ABC as niche-innovations and determining that these need to be aligned in a manner that supports the design effectiveness of each, it has become increasingly evident that each niche-innovation of ABC is ultimately dependent on one another. As this technology continues to develop, additional niche-innovations will come to fruition as a product of the shortcomings of some of the previous niche-innovations, and this cycle of constant improvement will likely take this advanced technical system from occasional specialized applications to the vast majority of bridge rehabilitation projects.

Next, by assessing the progress of Accelerated Bridge Construction development in the construction industry, it is evident that this behavior of the socio-technical regime is rooted in the systemic effort to solve cultural transportation issues. Many people may overlook the fact that events as simple but frustrating as traffic detours, or more severe events such as a construction worker being struck and killed by a vehicle on the side of the road, are shortcomings in the culture of our society, in the sense that these occurrences have become "normal." And while it is clear that a traffic detour is not nearly the same level of severity as a construction worker death, these situations can stem from the same problem. Accelerated Bridge Construction aims to solve both of these cultural issues, which is reflected in the corresponding socio-technical regime's research in transportation efficiency and safety.

Lastly, using Geels' multi-level perspective to analyze the socio-technical landscape of ABC, it has become clear that the public's perception can influence the path of implementation. While it is worth noting that the media portrayal of this emerging technology following accidents, such as the previously mentioned FIU bridge collapse, has negatively impacted the public's perception, the stability of the socio-technical landscape will not allow singular events to undermine the innate value of this technology. This stability, which comes as a result of the balance between government-run and academic research and implementation programs, along with the variety of credible resources available to the public, will allow the emerging technology of Accelerated Bridge Construction to potentially become the primary method of bridge rehabilitation as it continues to develop.

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