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From Railroads to Electrified Roadways: How Lessons from United States Engineering Education Can Power Tomorrow's Infrastructure

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Introduction

Some of the largest engineering projects in the United States have been national infrastructure projects such as the creation transcontinental railroad and the interstate highway system. These large-scale infrastructure projects require a combination of training new workers and helping the existing workforce to develop new skills to bring those projects to reality in an effective and efficient manner. With the advent and popularization of modern electric vehicles (EVs), United States infrastructure is facing another potential change involving the electrification of roadways, mass installation of charging stations, and development of dynamic wireless power transfer (DWPT) systems. We, as engineering educators, need to prepare the current and future workforce to be able to meet the demands of electrifying infrastructure and to address the challenges associated with such a large change. In this paper, we investigate the history of how engineers and other workers were educated and trained for previous national infrastructure projects and highlight the problems and solutions faced at the time. Additionally, we show ways to leverage this history to improve the current education of engineers and other workers for the purpose of electrifying roadways.

As of 2023, 18% of the world's new cars sold were EVs, including battery-electric and plug-in hybrid vehicles, as well as 10% of new cars sold in the United States [1]. In China, 38% of new cars are EVs and in Norway 93% of new cars are EVs. In 2023 alone, there were 13,800,000 new EVs sold worldwide and 1,390,000 new EVs sold within the United States [1]. One estimate predicts the yearly number of new EV sales in the United States will increase to 2,320,000 by 2029 [2]. It is clear that EV adoption is here and will only increase as society transitions away from fossil fuels, or at least away from fossil fuel powered vehicles. To accompany this rise in EV adoption, there has been a mass installation of charging ports with over 192,000 publicly accessible charging ports as of August 2024 and thousands more being installed regularly [3] (U.S. Department of Transportation Federal Highway Administration, 2024). Many researchers, such as the ones working for the National Science Foundation (NSF) funded engineering research center Advancing Sustainability through Powered Infrastructure for Roadway Electrification (ASPIRE), believe that we need a more holistic approach to electric vehicle adoption and develop an electrified infrastructure to support the mass adoption of EVs [4]. However, the electrification of United States infrastructure is a challenge that requires the training of new engineers and trade workers to develop, install, and maintain the electrified roads.

An Abbreviated History of Engineering Education in the United States

Before looking at the specifics of how engineers were educated for large infrastructure projects, it is useful to provide a very general overview of the history of engineering education in the United States. It should be noted that the goal of this paper is not to provide a detailed history of engineering education or the history of any one particular infrastructure project; rather, we aim to highlight problems and solutions related to educating engineers for these infrastructure projects and applying those lessons from history to our modern efforts in expanding electric vehicle infrastructure. Going back to the early 1800s and the onset of a collegiate approach to engineering education over the apprenticeship model, United States engineering education was beginning to adapt to public needs with the military academy West Point training 30% of the engineers that worked on public works including railways and canals [5]. Later in 1835, Rensselaer Institute, now Rensselaer Polytechnic Institute, would graduate the first class of students with an authorized degree in Civil Engineering, which was unique within the United States and Britain at the time [5]. As the United States colonized further westward, the need for engineers grew as well and motivated the passing of the Morrill Land Grant Act of 1862. The Morrill Act states that land will be given to the states to develop or sell to create colleges for the specific purpose of teaching agriculture and the mechanic arts [5], or, in other words, to teach engineering. As a result, the number of engineering schools increased from 21 in 1862 to 70 in 1872 [5].

Accompanying the boom in engineering colleges was a need to create standards and continuity across the colleges, which led to the creation of The Society for the Promotion of Engineering Education (SPEE) in 1893 [6]. After several decades of research into various approaches to engineering education, creating documents such as the Mann Report in 1918 and Wickenden Investigations from 1923-1929, SPEE began to support an accreditation model which led to the creation of a new organization, the Engineers' Council for Professional Development (ECPD) [6]. The ECPD was also a strong advocate for engineering licensure but failed to align various disciplinary based engineering professional societies around a definition of professionalism [7]. This failure caused some members of the ECPD to create a new organization called the National Society of Professional Engineers (NSPE) that was able to advocate for professional engineering licensure as part of their broader anti-worker and anti-union efforts [7], [8]. Eventually, SPEE would be succeeded by the American Society for Engineering Education (ASEE) in 1946 and the ECPD would be transform into the Accreditation Board for Engineering Technology (ABET) in 1980, two organizations that have significant influence in engineering education today [6].

As engineering education has become more intertwined with policy and accreditation over the last century, there have been five major shifts in engineering education [9]. These include shifts towards engineering science as well as outcome-based education and accreditation that have already occurred. Shifts towards engineering design emphasis, applying educational research to engineering education, and integration of modern information and communication technologies are happening presently [9]. Some of these shifts are intentional, such as the mass adoption of ABET accreditation, but some are more organic such as the use of computers in the classroom.

Historical Infrastructure Education Trends

One of the first major national level infrastructure projects in the United States was the installation of the transcontinental railroad, beginning in 1862. The scale of this project exceeded what self-trained engineers were able to accomplish and many new engineering schools were established as part of the new demand for scientifically trained engineers while the Morrill Act simultaneously provided funding to states for those new schools [5]. In 1850, the United States census only counted 572 civil engineers [10] and about 300 engineers had graduated from 1835 to 1866 [5], both of which is representative of a lack of access to formalized engineering education for most people. Grayson also highlights how during the mid-19th century most engineers were still trained on-the-job but those with an engineering degree were able to find jobs working in railroad and bridge construction [5]. The primary problem facing engineering education at this time was simply producing enough skilled engineers to meet the demands of industry. While engineers were involved with the planning and design of the railroads, they were not the workers responsible for the construction. Many immigrant workers were key in building the transcontinental railroad with more than ten thousand Chinese workers performing the physical labor for the project. Poor working conditions killed an uncertain number of Chinese laborers, with a lack or reporting from the time creating a wide range of estimates between 50 people and 2000 people killed [11].

Moving into the beginning of the 20th century, the adoption of early internal combustion engine cars began to grow, and the need for highways and roads changed accordingly. Before 1910, highway engineering education spent from two to five semester hours on class specifically about roads and pavements, but the curriculum was otherwise nearly identical to general civil engineering curriculum [12]. The First National Conference on Education for Highway Engineering and Highway Transport, held on November 26th, 1920, began to address the issues associated with highway engineering of the time and encouraged universities to teach about highway engineering [13], [14]. This conference was held at the University of Pittsburgh because they had recently developed a highway-transport laboratory in order to conduct highway engineering and transport research. The published proceedings for the first conference are fairly short and consist of several one-to-two-page briefs written by leaders in the discipline including Roy D. Chapman, Vice President of the National Automobile Chamber of Commerce; S. B. McCormick, Chancellor of the University of Pittsburgh; H. E. Hilts, Principal Assistant Chief Engineer for the State Highway Department; A.G. Batchelder, Executive Chairman of the American Automobile Association; P. P. Claxton, United States Commissioner of Education; Thomas H. MacDonald, Chief of the United States Bureau of Public Roads. Despite the brevity of the proceedings, the reported attendance was about 2000 people [13].

The main problem identified at the First National Conference was the need for vocational training for foreman, road supervisors, chauffeurs, and auto mechanics. They suggested two solutions to this problem, first that employers be responsible for training chauffeurs, and second that public schools should teach day and night courses for chauffeurs and auto mechanics [13]. To add some historical context, the Ford Model T was still in production during this meeting which meant that the vast majority of people had no experience driving a car and some people relied on chauffeurs to drive for them. While developments in road engineering had occurred prior to this conference, this era presented an opportunity for greater expansion of roadways and for the adaptation of roads to accommodate motor vehicles. A major concern for the conference attendees was simply teaching people how to operate a motor vehicle and to do so safely. One of the briefs included in the proceedings, titled “Methods of Teaching Accident Prevention in Detroit” by Harriet Beard the Supervisor of Safety Education for Detroit Public Schools, describes how children were often victims of traffic accidents because of a lack of education around safe driving practices, resulting in 96 deaths from August 1, 1918, to August 1, 1919 [15]. Beard continued to describe how there were no textbooks for this sort of education, so they relied on detailed records from the police department to develop an understanding of who was getting injured in motor vehicle accidents and the circumstances around the accident [15]. The immediate safety concerns needed to be addressed before broader highway planning could truly begin.

The Second National Conference on Education for Highway Engineering and Highway Transport, held in 1922, was a much larger affair with the conference lasting three days instead of one and the proceedings growing from 20 pages in length to well over 200. For this conference, President Warren G. Harding wrote to the organization saying, "The whole program of transportation – in all its phases it must be regarded as that of a single problem, presenting a great many aspects…" [14, p. 12]. Dr. Walton C. John, Secretary of the Highway Education Board, recognized the first aspect of this multifaceted problem was the construction and maintenance of thousands of miles of highways, railroads, roads, and other pieces of infrastructure, but he also highlighted aspects of agricultural and urban development, rural education, industrial development, national defense, and social life [14]. John summarize the solutions presented at the Second National Conference into the following eight points: (1) greater research on highway problems, (2) improved courses based on modern research, (3) "the improvement of highway engineering and highway transport teaching staff" [14, p. 16], (4) strengthening professional attitudes, (5) increased employment of highway engineers by from municipal to state levels, (6) cooperative studies between leaders of different transportation groups, (7) "the study of foreign practices in highway matters" [14, p. 16] and (8) "the careful study of highway and transportation legislation" [14, p. 16].

One particularly interesting committee report from the Second National Conference addressed the sociological aspects of highway transportation and the lack of accessibility most people, especially those in rural communities, had to modern amenities of the time such as hospitals, schools, trade, and even amusement [16]. The committee stated that a highway engineer should be trained to "take into account the social requirements of the localities through which his roads are to pass – and his influence should be felt in promoting the new groupings of population which are often needed to bring people the greatest social satisfaction" [16, p. 222]. The committee even touched on a utilitarian understanding of road access by arguing that "Where only a limited number of miles of improved road can be built the important problem is to know where this road can be built to serve the greatest number of people" [16, p. 222] and that "Personal and political influence should not be considered in locating a public highway" [16, p. 222]. They also argued that this sociological aspect of highway engineering should not only be taught to the highway engineering students, but to the construction workers as well [16].

The final major infrastructure project that has major relevance to revamping and electrifying modern infrastructure is the federal interstate highway project. The interstate highway system represents approximately 1% of all road milage in the United States but handles approximately 26% of all miles driven [17], an indication of their importance. With the passage of the Federal-Aid Highway Act in 1956, construction of the interstate highway system was a massive undertaking that involved building thousands of miles of roads across challenging terrain [18]. Early-career civil engineers who began to work on highways after graduation needed to be trained in practical skills by the older engineers who "built roads from experience, not from books" [18, p. 40]. Following the trend identified by Froyd et al. [9], these new engineers were trained in the science and theory of engineering but lacked the experience and know-how that comes from actually working on the roads. Part of this on-the-job practical training was also the professional socialization of civil engineers to focus on the technical aspects of building the highway while ignoring or minimizing the social and political aspects of building the roads [18]. Previous issues of access to education had been dramatically reduced after the many decades of creating engineering programs at universities, but it was replaced with an incongruity between what was taught to attain their degree versus the practical skills needed to perform the job.

Lessons to be learned

From the first two National Conferences on Education for Highway Engineering and Highway Transport, the attendants identified major problems and solutions associated with highway engineering including the need for vocational training, safety concerns, professional development, the need for engineers to work with and within local government, and the need to improve the instruction of highway engineering through course and instructor development. They also identified the need to improve and increase research on a variety of highway issues including legislation and international approaches to road development,

The immediate safety concerns presented by Harriet Beard [15] at the First National Conference on Education for Highway Engineering and Highway Transport reflect some modern concerns over the safety of EVs, specifically around the lack of noise they produce and how to extinguish large battery fires in a car wreck. EVs do not have the engine hum that drivers and pedestrians are used to, which can result in accidents with people who cannot see or hear the EV. As a result, part of Pedestrian Safety Enhancement Act required EVs to make sounds to alert pedestrians when the vehicle is moving below 18 mph [19]. The large batteries in EVs also present a safety concern because of the dangers of electrical fires. While cars that run on an internal combustion engine do need to carry a tank of flammable liquid as fuel, EVs have a risk of starting large lithium-ion battery fires with different practices to quench [20], [21]. These are safety concerns for vehicles, but they also reflect safety concerns for the infrastructure. Gas stations already have fire suppression systems, so similar suppression systems may need to be installed in areas with a high concentration of EV charging stations. In addition to general electrical safety, workers and technicians need vocational training on the specific fire hazards associated with EVs and EV charging. Engineers also need to consider these same dangers in their designs and need to build emergency safety measures into electric infrastructure. Regulations that establish safety standards and codes, such as the one that requires a minimum sound level for EVs, can help provide engineers with a framework and baseline for safety they can utilize as well as common ground for universities to teach safety to students.

From the solutions presented at the Second National Conference on Education for Highway Engineering and Highway Transport by Dr. Walton C. John [14], all eight could be directly applied to electrifying roadways and EV infrastructure. Amplifying research, improving curriculum based on that research, and training instructors to teach this new research-based curriculum are solutions that can apply to almost any new technology that is being adopted. Interdisciplinary research, such as what is done at ASPIRE, can provide instructors with information on EV infrastructure technology they are developing and can foster collaboration. We cannot expect engineering students to be ready to design, implement, and maintain electrified roadways if they are not taught how to do so by knowledgeable instructors who are utilizing modern infrastructure research in their curriculum, such as teaching students about DWPT systems. As for government employment, federal and state governments are incredibly important bodies for funding and implementing large interstate infrastructure projects. Working to build roads across localities, states, and between states requires a certain amount of federal oversight and funding, as seen in both the development of railroads and of the interstate highway.

Rose and Seely [18] mentioned that building the interstate highway system required older engineers needed to train new civil engineers in the practical skills of highway engineering despite having just graduated with an engineering degree. While some amount of on-the-job training is expected for any new engineer, there are opportunities to reduce the amount of post-graduation training needed for early-career engineers to be effective at their job. The leaders of the First National Conference on Education for Highway Engineering and Highway Transport also recognized the role employers should take in training people but specified that it should be paired with some sort of public education as well [13]. Engineering education is currently oriented around teaching students the science behind engineering in order to meet accreditation requirements as well as design [9], but more practical applications of engineering could be reintegrated into engineering curriculum. For example, academia could leverage industry connections to have students visit active work sites or build more direct pathways for student internships.

Returning to the report on sociological impacts of highways, the engineering educators of the 1920s understood the importance of developing roads to benefit the people more than anything and to do so in a manner that connects communities without disenfranchising people who lack access [16]. When discussing electric vehicle infrastructure, a very similar conversation around widespread adoption, access, and development arises. The infrastructural needs between urban, rural, and suburban communities all vary, especially when discussing EV infrastructure. In Canada, the charging behavior public chargers in rural and urban communities differed enough that it was not possible to generalize usage, which suggests the need for area-specific approaches to EV infrastructure development [22]. The modern need for a regional specificity for EV infrastructure reflects what Galpin et al. [16] proposed in 1922, that engineers should be working with the localities to ensure that they are meeting the needs of the people and do so in a manner that will help the most people while connecting communities together. A local approach also helps engineers respect consumer autonomy by not forcing a solution to a problem they may not have.

More than just construction, the maintenance of roads was also a significant aspect of the problem of transportation identified in 1922 [14]. This importance of maintenance is echoed in modern times by Russel and Vinsel [23] who argue that there is currently too much emphasis innovation within engineering and that people also need to focus on maintenance. They highlight how the United States is currently due for maintenance with public concerns over failing infrastructure, low workers' wages, and regular natural disasters. The modern EV was innovative during its initial public acceptance but there was not an innovative approach to infrastructure to accompany the societal shift towards EVs and away fossil fuel powered vehicles. Currently, there are many researchers working on creating innovative EV infrastructure solutions including DWPT systems so EVs are able to wirelessly charge while driving down the highway. With ASPIRE, a test strip of a DWPT road has been installed in Indiana, near Purdue University, which is a major step towards testing innovative EV infrastructure [24]; however, there also needs to be equal emphasis spent on teaching engineers how to maintain these electrified roads. Additionally, the wide range of climates in the United States mean that the maintenance needs for the roads will vary geographically, such as differences in rain or snow fall. Just like installing the infrastructure, engineers need to work with local communities to meet their maintenance needs.

Conclusion

As society transitions towards EVS, we also need to transition our infrastructure towards electrification. This is not the first time that the United States has faced the challenge of large-scale infrastructure development, so we should learn lessons from history. Our paper provided historical insight into the problems and solutions associated with training engineers for previous national-scale infrastructure projects and showed that engineering educators can learn from the past to aid current efforts.

Some of the current initiatives leading the charge for electrifying infrastructure come from ASPIRE and from the National Renewable Energy Laboratory (NREL). The engineering research center ASPIRE has partnered with universities and industry members across the United States to conduct research into electric infrastructure. In addition to the test strip of a DWPT highway ASPIRE has installed in Indiana, they have also installed test strips in Florida and Utah with Utah also having a test 1 MW static charger [25]. NREL is also conducting electric vehicle infrastructure research but with more emphasis on how high-power charging and increased demand will impact the electric grid [26]. The United States federal government has also invested $5 billion in proliferating EV chargers through the National Electric Vehicle Infrastructure Formula program, $1.25 billion in charging and fueling infrastructure grants, and several more billion in related programs for reducing carbon emissions from cars and battery technology for cars [27]. These efforts show institutional commitment towards electric infrastructure with significant amounts of funding that could employ engineers as suggested in the 1920s and done for the interstate highway.

EV infrastructure involves new technologies but many of the fundamental problems around infrastructure development and highway engineering education have not changed. Engineers and engineering educators can rely on previous iterations to support current efforts. Unlike the 1800s and early 1900s, engineering programs and universities are mostly able to meet the demand for new engineers, so our efforts should focus on ensuring the quality of their education and collaboration with the researchers. Many new engineers will be needed to make the transition to EVs a reality, but engineering students need to be properly educated on the latest research by well-trained instructors. Engineering educators should be partners with organizations like ASPIRE and NREL to bring learning about the latest technology into the classroom. Sociological perspectives can also be integrated into the curriculum, as suggested by Galpin et. al [16], to give engineering students a more holistic understanding of how infrastructure impacts people.

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