STEM Outreach to K-12 Students: The Root of Railway Engineering Education

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ABSTRACT

Demand for graduates with rail expertise remains strong in North America, particularly in engineering and technical fields. Over the past decade, the AREMA Railway Engineering Education Symposium and rail-focused University Transportation Centers have slowly reestablished a railway engineering academic community. Railway courses are now offered at two dozen universities in the United States, and, for the first time in decades, several universities offer specific degrees in railway engineering. Despite this progress, challenges remain, such as raising student awareness of rail industry career paths. Since most railway engineering courses are senior-level electives, many students are already committed to other engineering disciplines before they are exposed to railway concepts. To raise student interest in rail courses and satisfy industry demands for interns, students must be introduced to railway concepts before they decide on the direction of their studies. One approach to directing more rail-aware students into engineering programs is rail-themed outreach to K-12 students. Railways still hold a fascination for many young people and as complex, multidisciplinary systems, numerous interesting science, technology, engineering and math (STEM) concepts can be demonstrated through the lens of railway transportation. Interactive rail-themed classroom activities can illustrate STEM topics while highlighting rail career opportunities and reinforcing railway safety. This paper reviews rail-themed K-12 STEM outreach activities being undertaken by universities and the strong partnerships between industry and academia required to grow future generations of railway professionals.

Keywords: Railroad engineering education, industry-university cooperation, K-12 STEM education, outreach

INTRODUCTION

The North American railway network provides safe, reliable and efficient movement of people and products that drives economic development. A well-functioning rail transportation system is ultimately dependent on a supply of skilled rail transportation leaders to plan, design, operate, maintain and manage the rail system of the future. However, only a small number of rail academic programs in North America are engaged in rail-related research and teaching courses to educate the next generation of railway professionals (*1*). Over the past decade, collaboration between academia and industry has succeeded in expanding the number of university courses on railroad topics (*2*) and, for the first time in several generations, university students in the United States can complete specific minors and full undergraduate and graduate programs leading to railway transportation engineering degrees. This progress has resulted in new challenges, namely recruiting a minimum number of undergraduate students with an interest in rail to sustain new education programs and meet industry demand for interns. Meeting this demand requires further collaboration between industry and academia to raise student awareness of rail industry career paths at an earlier stage of their education. One approach to directing more rail-aware students into engineering programs is rail-themed outreach to K-12 students. This paper briefly describes recently expanded railway engineering educational opportunities, and concentrates on rail-themed K-12 science, technology, engineering and math (STEM) outreach activities being undertaken by universities and the strong partnerships between industry and academia required to grow future generations of railway professionals.

REMERGENCE OF RAILWAY ENGINEERING EDUCATION AND NEW DEGREE PROGRAMS

The deterioration of the historical relationship between higher education and North American railroads, and subsequent decline of railway engineering education at the University level, has previously been documented (*3*). As early as 1980 it was recognized that the current level of railway engineering course content would not sustain long-term demand for railway engineering professionals (*4*). By the 1990s, most engineering graduates would obtain their degrees without any exposure to railroads. By the start of the 21st century, less than 15 percent of North American universities included railway engineering as a topic in general transportation courses and less than three percent offered a separate course on railway engineering (*5*). In 2005, a survey of 500 engineers with five years or less of rail industry experience revealed that 84 percent had not received any college exposure to rail topics (*5*).

In the early 2000s, railway capacity projects required to support rapidly growing freight and passenger traffic created a sudden increase in demand for railway engineering professionals that academia was not equipped to meet (*6*). Planning and design of proposed high-speed rail systems slowly created additional demand for railway engineering talent while simultaneously capturing the imagination of many students (*7*). For the rail industry, the general demographic trend of an aging transportation workforce (*8*) was compounded by the decades-long lack of railway engineering course content at the university level. As the senior project managers who had railroad engineering in their academic programs continue to retire, the railroad industry faces the prospect of all future rail design being inherited by a young generation of designers who have little, if any, academic background and domain knowledge of railroads (*9*).

Civil and transportation engineering professors interested in incorporating railway engineering material into their courses, and developing new courses devoted to rail, faced obstacles such as a lack of railway research funding, connections to railway industry professionals, and suitable teaching materials (*10*). To help faculty overcome these obstacles, the American Railway Engineering and Maintenance-of-Way Association (AREMA) developed the Railway Engineering Education Symposium (REES). Held every two years since 2008, REES brings engineering professors together with peers already specializing in railway engineering and with railway engineering professionals who work for railroads, governments, consultants and research facilities. The symposium provides the professors with lecture materials for incorporation into transportation classes. As a direct result of REES, railway engineering courses have been modified, enhanced or added at two dozen universities in the US (*11*).

The recent expansion of railway engineering course offerings for undergraduate and graduate students was aided by the formation of the National University Rail Center (NURail), a US DOT University Transportation Center, in 2012. NURail grants have provided critical resources to expand rail transportation education within the partnering universities. During the first three years of the NURail Center, between 2012 and 2015, the number of rail-focused courses at NURail partner institutions increased by 90 percent to a total of 34 rail-related courses, including new classes developed under NURail, such as Advanced Track Engineering and Railway Terminal Design & Operations at the University of Illinois at Urbana-Champaign, and Railroad Track Engineering at the University of Illinois-Chicago. The reach of these courses has also expanded as the number of online courses increased from three to ten over the same period.

At several campuses, the number of rail-focused courses has allowed for the development of full programs in railway transportation and engineering. For the first time in decades, several universities offer specific degrees in railway engineering:

- Penn State Altoona is currently the only institution in the US offering a specific Bachelors of Science (B.S.) degree in Rail Transportation Engineering (RTE). Located in Altoona, Pennsylvania, the RTE program is building off of a strong history of railroad research, testing and education in the Altoona community pioneered by the Pennsylvania Railroad. The RTE program provides a core civil engineering curriculum along with rail-specific courses covering railroad track infrastructure, mechanical department functions, signaling, and train operations. In 2015, Penn State Altoona graduated their first class of RTE students, and in 2017 the program was formally accredited by the Engineering Accreditation Commission of ABET (Accreditation Board for Engineering and Technology).
- In Fall 2016, Michigan Technological University (Michigan Tech) introduced a Minor in Rail Transportation. The eligible courses for the minor were selected based on the input from the Michigan Tech Rail Transportation Advisory Board (RTAB). Designed to be multi-disciplinary in nature, the coursework combines general railroad engineering and transportation logistics courses with discipline-specific courses considered relevant to graduates seeking careers in the rail industry.
- In Fall 2018, the University of Illinois at Urbana-Champaign will inaugurate a new Master of Engineering (M.Eng.) in Railway Engineering degree program. The three-semester interdisciplinary program is targeted at students who want to gain greater depth and breadth in railway civil, mechanical and electrical engineering topics through additional rail-focused coursework prior to embarking on rail industry careers. Although Illinois has been engaged in railway education activities continuously since 1898, the M.Eng. program will mark the first time students can formally pursue a specific railway engineering degree at Illinois since 1947. At that time, due to declining interest, the separate Railway Engineering Department was moved into the Department of Civil Engineering and the railway educational program became an area of specialization within the undergraduate and graduate civil engineering degree programs.
- Others institutions offering multiple railway courses, such as the University of South Carolina, have developed graduate certificate programs in railroads that serve as a pathway to full Masters of Science programs with a focus on railway engineering topics.

The emergence of rail-focused elective courses and new degree programs in railway engineering at multiple institutions has resulted in a new challenge: recruiting sufficient numbers of interested students to sustain the investments in faculty and other resources required to offer fail-focused courses and degree programs.

RECRUITING STUDENTS TO THE ACADEMIC RAILWAY INDUSTRY PATHWAY

While railways still fascinate many young people and youth continue to be involved in model railroad and other railway enthusiast hobby activities, only a very small minority of students seek out specific academic programs in railway engineering based on their personal interests. Unfortunately, the railroad industry is

rarely considered as a potential future career by today's youth, and heavy competition from other industries may hinder the recruitment of even those individuals who have expressed interest in railways. The small number of institutions offering rail-focused courses presents another obstacle to students with a strong interest in rail. Without a local university offering courses in railway transportation, students face the choice of paying higher out-of-state tuition to pursue their railway interests, or settling for a local program that is more general and not provide them with the rail domain knowledge, industry contacts and railway internships critical to securing a position in the railway engineering field after graduation.

As early as the late 1950s, it was recognized that declining use of passenger rail service and an overall decrease in railway employment in the US would diminish the number of youth inspired to pursue railway careers by vacation travel and family connections to railway employees (*12*). These trends continue to the present day. With little railway industry outreach to youth at the K-12 level, the vast majority of incoming engineering students enter university without any awareness of potential careers in the rail industry. Students most often receive their first formal exposure to railway concepts through lectures in introductory transportation engineering courses at the junior and senior levels. These lectures are key to sparking student interest in the railway field and, where available, leading students to enroll in senior-level elective courses specifically on railway topics. However, faculty engaged in delivering these senior-level rail-focused courses often observe that by the time most students are exposed to railway engineering concepts during senior year, it is frequently too late to steer them into careers in the rail industry. Students are often committed to other employers through previous internships, do not have program flexibility to add rail courses, fear limiting their career opportunities by becoming "too specialized" in rail, or have influential parents that perceive railways as a "low-tech" dying industry.

It is clear that to provide the rail industry with the volume of rail-aware students necessary to fill entry-level positions for graduating engineers, and supply rail-focused courses and degree programs with a sustainable supply of enrollees, students must become introduced to railway engineering concepts at earlier junctures on the university pathway to the railway industry (Figure 1). The rail industry relies heavily on faculty engaged in railway education and research to play an integral role in meeting the demand for railway transportation professionals by guiding students through this pathway. Faculty may be aided in on-campus outreach to incoming freshmen by student groups, such as AREMA student chapters, to act as ambassadors and promote student awareness of the railway field. Engaging industry professionals through the AREMA student mentoring program can also help guide students with a developing rail interest through this pathway and into industry careers. However, students are not likely to seek out railway mentors until the later stages of their academic career or possibly not until grad school, limiting the effect of this program on overall enrollment in rail courses.

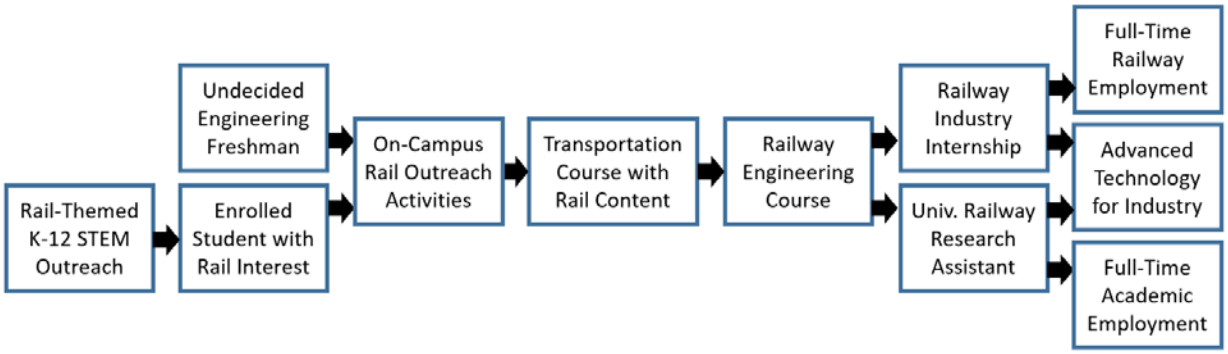

FIGURE 1: University pathway to the rail industry

RAIL-FOCUSED STEM OUTREACH

While outreach to incoming freshman engineering students is critical, to further increase the pool of potential students for rail-focused courses, degree programs and eventual industry careers, industry efforts to recruit students and promote the railway engineering field must move even earlier to the pre-college portion of the pathway to industry. To engage students at the pre-college level, railway-focused faculty and AREMA Student Chapters have engaged in outreach to students enrolled in kindergarten through grade twelve (K-12), typically through railway-themed Science, Technology, Engineering and Mathematics (STEM) activities. Promoting the STEM fields to K-12 students has been demonstrated to increase the number of high school students enrolling as freshman in related engineering programs (*13*). In particular, students who had research experiences in high school, who undertook an apprenticeship, mentorship or internship, and whose teachers connected the content across different STEM courses were more likely to complete a STEM major than their peers who did not report these experiences.

As an engineered system involving the movement of large heavy objects across infrastructure maintained to tight tolerances, railroad transportation lends itself to demonstrations of basic physics, engineering, mathematic and economic concepts through interactive hands-on activities. While demonstrating STEM concepts and incorporating engineering principles of design, testing and problem solving, these hands-on activities can also introduce students to specific railway applications, technologies and career opportunities. Additionally, railway-themed activities provide creative and design-related outlets in numerous engineering disciplines including civil, mechanical, electrical, environmental, computer science, and fluid mechanics. In this manner, rail-themed K-12 STEM activities provide a compounding benefit; not only do they increase student awareness of the broader engineering and technical fields, they also make students aware of specific careers in railway engineering and transportation. In the long term, increasing both the number of students entering engineering degree programs, and the fraction of them that are aware of the railway engineering field, will both serve to increase the number of students that engage with AREMA Student Chapters, enroll in rail-focused courses and matriculate in specialized railway degree programs.

Examples of Rail-Focused K-12 STEM Activities

The following list presents a number of rail-focused K-12 STEM activities that have been developed at various universities engaged in railway engineering education and research activities. The list is not intended to be comprehensive but instead to demonstrate that the activities can be centered on different railway functions from engineering to operations, and may relate to any number of civil, mechanical and electrical phenomena and their underlying fundamental STEM concepts in physics and mathematics.

- **Track Structure Construction**. Students use sand, aquarium gravel, balsa wood crossties, push-pin “spikes” and 3-D printed (or G-scale model railroad) rails to build a foot-long representation of the railway track structure on a cookie sheet. The students observe how, without the aquarium gravel “ballast”, the skeleton track structure is flexible and unstable. Using a spring scale, older students can measure the change in lateral resistance offered by the track structure before and after the ballast is added.
- **Drinking Cup Wheel-Rail Dynamics**. After demonstrating that a cup on its side will roll in a circle due to different rolling radii, students use plastic drinking cups and tape to assemble simple models of tapered railway wheelsets. The students are encouraged to arrange the tapered cups in different combinations and orientations and then test them by rolling them down a tangent and curved section of representative railway track. The students can observe how the proper tapered wheelset oscillates to negotiate the tangent and curved sections of track while other combinations are unstable, over-correct and “derail”.
- **Railway and Roadway Rolling Resistance**. This activity compares the rolling resistance of two model railcars: one fitted with standard steel wheels rolling on model railway track, and one fitted with rubber radio-controlled automobile wheels and tires rolling on the table. Students use a spring scale to measure the rolling resistance of the two railcars, demonstrating how the steel wheel on steel rail contributes to the overall efficiency of railway transportation. Older students

can change the weight carried by the railcars and the pulling speed to reveal different train resistance relationships.

- **Popcorn Railcar Size and Weight**. This activity demonstrates how the cubic capacity of railcars is optimally sized for the density of the freight commodity it is designed to carry. Containers filled with equivalent volumes of materials with different weights, such as plastic pellets, beans and metal bee-bees, or un-popped and popped popcorn, are used to explain concepts of volume and density. Students then fill two open-top hopper car models of different cubic capacity with granular materials of various densities to determine if the material fills the volumetric capacity ("cubes out") or, as measured by a kitchen scale, reaches the scaled-down railcar weight limit ("tares out").
- **Intermodal Race Game**. The purpose of this activity is to demonstrate the efficiency of "intermodal" railway transportation of shipping containers relative to transporting them on individual trucks. In the game, two students race to transport six wooden block "shipping containers" between a port and an inland terminal at either end of a long table. One student uses a single truck while the competing student uses a train consisting of a locomotive and three double-stack railcars. The truck, locomotive and railcars are all fabricated from Pinewood Derby car kits. Typically, in the initial stages of the race, the truck builds a lead making several round trips while the train requires time to load all of the containers. However, by transporting the all six containers in a single trip, the train quickly gains the advantage.
- **Wooden Railway Simulation**. In this activity, a small group of students work together to operate trains over a Bio-style wooden railway, earning revenue for every railcar they transport but also incurring expenses for crews and fuel. As the students are prompted to increase their profits, they attempt to run more frequent and longer freight trains, requiring capital investments in additional passing sidings and siding extensions on the single-track route. Students learn basic concepts of transportation and railway economics, railway operations, train dispatching, and railway capacity planning.
- **BRIO Classification Yard**. Using Brio-style wooden railway track and railcars, students construct a representative classification yard according to a schematic layout of tracks and turnouts. The students are then guided through the process of switching an inbound train of wooden railcars labelled by block color or number into the different classification tracks. The basic activity can be extended by reducing the number of tracks and explaining how multi-stage soring can be used to form more blocks on fewer tracks.
- **Track Circuits and Automatic Block Signals.** Sections of large-scale model railway track, signals and relays can be used to construct working models of the railway signal system. An example of such a display uses approximately five feet of track affixed to a base. The rails are divided into five block sections separated by four block signals. Batteries and relays are used to create track circuits that are shunted by a turned brass wheelset. Students can roll a wheelset across the track sections, see and hear the relays engaging and the progression of stop, approach and clear signal aspects behind the "train".
- **Locomotive Simulator.** Various commercial train simulators such as Run8, Trainz and Microsoft Train Simulator provide uses with an interactive, in-cab locomotive engineer perspective of train operations. When combined with a large flat screen display and special commercial desktop controllers that simulate actual locomotive throttle, brake, bell and horn controls, these software packages deliver an effective locomotive simulator experience. Experience suggests that simulations of commuter rail operations are most effective for student groups as each student can quickly take a turn accelerating the train, holding it at speed and braking to a (hopefully) precise stop at the next commuter platform.
- **Operation Lifesaver and Railway Safety.** While stimulating student interest in railways, it is also important to reinforce fundamental railway safety rules at grade crossings and that trespassing on railway right-of-way is extremely dangerous and is a crime. Operation Lifesaver can provide railway safety educational materials and guest speakers to complement rail-focused K-12 STEM activities.

Most of the activities listed above have several commonalities: 1) they encourage students to work together in small groups or as a team, 2) they encourage students to physically interact with scale models or representations of actual railway infrastructure and rolling stock, 3) students are encouraged to

formulate hypotheses or make decisions on the best design alternative or approach to a particular element of railway technology, and 4) they involve observation and measurement of different trials and potentially analyzing and interpreting qualitative and quantitative data. This latter point provides an opportunity to adjust the scope of activities for different age groups; younger students can focus on working through the activity and making qualitative observations or simple measurements while middle and high school students may make more detailed measurements and plot the data to reveal the form of underlying relationships. Several universities use these same activities as classroom demonstrations to accompany more detailed explanations of railway engineering phenomena within their rail-focused courses for matriculated students or short courses for industry professionals.

Rail-Focused K-12 STEM Outreach Programs

Many of the rail-focused activities briefly described in the previous section were developed as part of larger K-12 STEM outreach programs. Examples include the Summer Youth Program in Rail and Intermodal Transportation at Michigan Technological University, Engineering Open House and summer STEM Camp rail day at the University of Illinois at Urbana-Champaign, “Kid’s College” at Penn State Altoona and support of the Boy Scout “Railroading” merit badge at various campuses.

Michigan Technological University, in collaboration with the University of Wisconsin-Superior, has been running a week-long Summer Youth Program (SYP) in Rail and Intermodal Transportation. The SYP had six participants during its inaugural run in 2010, but has since expanded to attract up to 25 students from grades 9-11, nationwide. Much of the expansion occurred after NURail became involved with supporting the program in 2013. With NURail funding, Michigan Tech was able to match the 50-percent scholarship initially provided by industry gifts and a special focus was added to attract minorities to the program. A collaborative effort with Illinois and Hanson Professional Services has annually brought minority students to the program since 2014. The program includes classroom lectures, industry visits, and hands on activities. The highlight of the program has consistently been the numerous field visits to various industry facilities, including Lake Superior and Ishpeming Railroad, Halvor Lines (trucking company), CN ore/taconite docks, BNSF rail yard and North Shore Railroad Museum.

Each summer since 2015, the University of Illinois Rail Transportation and Engineering Center (RailTEC) has also hosted a “railway day” in cooperation with a local provider of STEM-focused summer camps. During the day-long event, RailTEC graduate students, faculty and alumni volunteer as guides for various rail-focused STEM activities as the campers rotate between activities. The Illinois AREMA Student Chapter has also taken these activities on the road to stage similar events at elementary schools in the communities surrounding campus.

Rail-focused STEM exhibits and activities are also staged by the University of Illinois AREMA Student Chapter each year at Engineering Open House (EOH). A two-day student-led event encompassing the entire engineering campus, EOH encourages K-12 students and the public to visit engineering labs on campus and experience hands on STEM activities. In addition to several of the activities listed earlier, the AREMA Student Chapter assembles a full-scale track panel inside the civil engineering building and uses it to explain various track components and track tool to the public. The Illinois student chapter has also partnered with CN, BNSF, Norfolk Southern and Central Japan Railway to have professional railroaders attend EOH to display train control and dispatching systems, hi-rail maintenance trucks, models of maglev trains and information on recent engineering and capital expansion projects. Since 2014, RailTEC has partnered with Hanson Professional Service to bring 25 minority and disadvantaged students from Springfield, Illinois with strong academics and an expressed interest in STEM fields to tour EOH while accompanied by RailTEC graduate students. Several past attendees from Springfield have gone on to enroll in civil engineering degree programs and hold summer internships with Hanson.

In 2017, Penn State Altoona launched a one-week Railroad Engineering program for 11-14 year-old students as part of the annual “Kid’s College” hosted throughout the summer in Altoona. This program will continue each summer, with the goal of increasing student participation each year. During this week-long half-day camp, RTE faculty worked with student assistants to offer an interactive program using several of the K-12 STEM activities listed in the above section. Starting in 2018, Penn State plans to

incorporate 360-degree virtual learning into the Kid's College program. Students will use virtual reality headsets to take virtual tours of various railroad industry locations in both the US and Europe. In addition to the annual Kid's College, the RTE program has worked with other departments at Penn State Altoona to offer a railroad engineering module for a "women in engineering" STEM program for junior high students. The Track Structure Construction activity was used for this program, reaching 40 female junior high students from several schools from the Altoona area.

A final nationwide opportunity to engage in rail-focused outreach to youth is through the Boy Scout Railroading merit badge. The merit badge requirements encourage scouts to explore various facets of the railway industry. Local scout troops are often in need of volunteers with a railroading background to help guide scouts through the Railroading merit badge requirements. The AREMA Student Chapters at Michigan Tech, Illinois, and Penn State have each helped organize Railroading merit badge clinics where scouts can learn about railroads and complete the badge requirements in a single day under the guidance of rail-focused undergraduates, graduate students and faculty instructors.

CONCLUSION

In order for the railroad industry to compete with other engineering fields in recruiting top talent, outreach must begin at a young age. Lessons from active STEM programs can help inform industry and academia in best practices for fostering interest that will lead to future workforce development. Several Universities and AREMA affiliated companies have begun to adopt this long-term vision. The University of Illinois, Michigan Technical University, and Penn State Altoona, among others, have worked to advance K-12 outreach through various initiatives. However, additional collaboration among industry and academia is still needed to generate the level of exposure and interest in railroad engineering required to meet future workforce demands. Both public and private investment will be required to advance this collaborative effort as K-12 outreach programs provide exposure to railroad engineering through creative, hands-on, and technology related initiatives. Just as railroads conduct long-term planning for capital investment, similar planning is needed for developing human capital that will grow to become the engineering professional workforce of the future.

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REFERENCES

1. Lautala, P.T., C.T. Dick, D. Rizos and D.B. Clarke. Toward the Next Generation of Railroad Professionals – Collaboration by NURail and Rail Industry. In*: Proceedings of the American Railway Engineering and Maintenance-of-Way Association Annual Conference*, Minneapolis, Minnesota, September 2015.

2. Lautala, P.T. and C.T. Dick. Railway Engineering Education Symposium: Evolving to Rebuild a Growing Rail Academic Community. *Transportation Research Record: Journal of the Transportation Research Board, No. 2608*, Transportation Research Board of the National Academies, Washington, DC, 2017, pp 96-104.

3. Barkan, C.P.L. Building an Education Infrastructure for Railway Transportation Engineering: Renewed Partnerships on New Tracks, *TR News,* Vol. 257, 2008, pp. 18-23.

4. Patton, E.P., C.J. Langley, Jr., and M.S. Bronzini. Reviving Railroad Education in the United States: Programs for the 1980s and Beyond. *Transportation Research Record: Journal of the Transportation*

Research Board, No. 748, Transportation Research Board of the National Academies, Washington, DC, 1980, pp 5-12.

5. Lautala, P.T. From Classroom to Rail Industry – A Rail Engineer in the Making. In*: Proceedings of the American Railway Engineering and Maintenance-of-Way Association Annual Conference*, Chicago, Illinois, September 2007.

6. Lautala, P.T. What the Railroad Industry Needs and Expects from Higher Education: Meeting the Needs. *Transportation Research Record: Journal of the Transportation Research Board, No. 2329*, Transportation Research Board of the National Academies, Washington, DC, 2013, pp 32-39.

7. Hernandez, P.D. and P.J. Haas. Estimating Workforce Needs for High-Speed Rail in California and the United States. *Transportation Research Record: Journal of the Transportation Research Board, No. 2328*, Transportation Research Board of the National Academies, Washington, DC, 2013, pp 25-31.

8. ICF International. *Strategies to Attract and Retain a Capable Transportation Workforce*. National Cooperative Highway Research Program, NCHRP Report 685, Transportation Research Board of the National Academies, Washington, DC, 2011.

9. Qinetiq North America. *A Guide to Building and Retaining Workforce Capacity for the Railroad Industry*. National Cooperative Rail Research Program, NCRRP Report 2, Transportation Research Board of the National Academies, Washington, DC, 2015.

10. Lautala, P.T. and W.J. Sproule. Rebuilding Railroad Engineering Education in the United States with Industry-University Partnerships. *Transportation Research Record: Journal of the Transportation Research Board, No. 2109*, Transportation Research Board of the National Academies, Washington, DC, 2009, pp 37-44.

11. Lautala, P.T., C.T. Dick, J.L. McKinney and D.B. Clarke. Railway Engineering Education Symposium (REES) - Universities and Industry Collaborate to Develop Railway Education. In: *Proceedings of the 2013 ASME Joint Rail Conference*, Knoxville, TN, April 2013.

12. Huffman, W.H. One Way in Which Committee 24 is Interesting Students in Railroading. In*: Proceedings of the American Railway Engineering Association Annual Conference*, 1958.

13. National Research Council. *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*. Committee on Highly Successful Science Programs for K-12 Science Education. Board on Science Education and Board on Testing and Assessment, Division of Behavioral and Social Sciences and Education. Washington, DC, 2011.