Survey of Future Railroad Operations and the Role of Automation

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In the past decade, freight rail automation systems have made significant advances. The objective of this work was to elicit ideas from the railroad industry about future automation systems and their impact on future operating configurations (such as the roles of human operators). A Dephi survey was administered in two rounds to industry leaders (Class I railroad managers and General Electric transportation senior engineers). The industry was generally found to be open to new operating configurations and to see increasing automation technology as key to achieving future benefits. However, there are significant concerns around training, deskilling, and the current development process. Several solutions to each of these problems were ranked by participants in order of perceived effectiveness. The implications for the development of rail technology and opportunities for future research are discussed.

To improve operational efficiency (including energy use) and safety, disparate in-cab automation technologies have been widely deployed by freight railroads in recent years. These technologies have largely been applied without any fundamental changes to the operating configuration of the rail transportation system as a whole (e.g., train crew roles and responsibilities). As these advanced controls and automation technologies are integrated into the locomotive and assume control of some functions, significant operational configuration changes become possible.

The goal of this work was twofold: (*a*) elicit attitudes toward and concerns about future automation technology and (*b*) start a discussion about future operating configurations in the freight rail industry. The study aimed to gain perspective on existing safety automation systems, such as Positive Train Control (PTC), as well as efficiency automation, such as General Electric's Trip Optimizer. The study investigated the impact these ideas might have on possible future configurations by surveying two distinct expert groups: railroad business leaders (e.g., vice presidents of operations) and automation system developers (e.g., systems and controls engineers). The input from these experts provided valuable information about the direction the industry may take in the future and the perceived likelihood of acceptance of various technologies.

Eliciting expert knowledge is a challenging task and many methods have been proposed (*1*). There are two significant drawbacks to any face-to-face method. The first is that anonymity is lost and there may be some hesitation to participate in these kinds of discussions. The second is that methods that require in-person interactions must necessarily be performed at a single organization at a time, thus limiting the interaction required to determine an industrywide consensus. Furthermore, the logistics and costs associated with facilitating several sessions may be prohibitive. One method that overcomes these issues and is particularly suited to eliciting predictions about the future is the Delphi method (*2*).

The Delphi method involves a questionnaire distributed to the group of experts over several rounds. With each round, the previous responses of all the expert respondents are anonymously provided to the group in the form of new or modified items on the questionnaire. Experts who have extreme views may be asked to explain their reasoning to be considered by the remainder of the group. In subsequent rounds, individuals whose responses continue to remain in the extreme are asked to provide rebuttals or a description of why the others' reasoning was not convincing. These reasons and rebuttals are further passed along to the group in the subsequent round of questionnaires along with any clarifying or probing questions added by the research team. The size of the groups varies between 10 and several hundred, but is typically significantly fewer than 40 individuals (*3*).

In many Delphi studies, the opinions of the group of experts converge as the rounds progress. However, even if the opinions do not converge, the sequence of responses helps to clarify the perceived issues and differing camps of thought (*4*). Although there is some debate as to the mechanism of the convergence [e.g., Van Dijk (*5*)], this method is the only known one that provides anonymous, substantial, and fair dialogue between all participants over a sustained period. The Delphi method also provides increased engagement and opportunity for critical thinking between rounds, when it is properly designed and executed (*6, 7*). The Delphi method has been used many times for the elicitation of technological trends in general [e.g., Gordon and Helmer (*8*)], the future of automation systems [Martensson (*9*) as cited in Martin et al. (*10*)], the desirability of alternate future scenarios [e.g., Tapio (*11*)], and predictions regarding transportation systems [e.g., Svidén (*12*); Piecyk and McKinnon (*13*)].

STUDY DESIGN

The invited participants were railroad company representatives (i.e., Class I railroad companies) and individuals from General Electric (GE) with extensive knowledge of the railroad industry and experience with rail automation systems (e.g., senior systems engineers and controls engineers involved in the design of a leading

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energy management system, Trip Optimizer). Eight participants from railroads were invited along with six participants from GE. Each participant received a letter explaining the purpose of the project and an invitation to participate. The survey was conducted electronically; a hyperlink was sent to the participants via e-mail. Participants were encouraged to participate in Round 2 even if they had not submitted a response for Round 1. After reading and signing the consent form, the participants provided basic biographical information before proceeding to the main survey response items. The experimental procedures and survey instruments for each round were approved by Massachusetts Institute of Technology's Committee on the Use of Humans as Experimental Subjects (Protocol #1406006431).

The study team utilized a modified Delphi method for this study. In Round 1, the prompts were designed to elicit reactions to a series of potential future scenarios. The scenarios were intended to be disparate in nature and futuristic. The questions were largely open ended, allowing the respondents to provide as much or as little information as they desired. In addition to biographical information, the following questions were posed:

1. Describe at least six desired features of future rail automation technology.
2. How would you measure the success of future rail automation systems?
3. List your concerns, and possible complications, regarding increasing amounts of automation technology for rail.
4. Describe your prior experiences with the introduction of rail automation technology.
5. Consider an operational scenario in which the traditional roles of train crews and automation systems are redesigned, such that some portion of the crew is now able to be located remotely (i.e., not on the locomotive). Describe at least three functions that you think could be performed by the remote crew members.
6. Describe at least three functions that you think should be retained by the local crew members.
7. What new functions would be required by the automation system to support the kind of remote–local configuration you described previously.
8. List your concerns about the remote–local configuration you described previously.
9. List the likely benefits resulting from the remote-local configuration you described previously.
10. What is the likely time it would take for the industry to adopt such an operational scenario?
11. Describe the reasoning behind your estimate.
12. Describe an alternate future operational configuration that you feel is more likely to be adopted than the idea of allowing some portion of the crew to operate remotely.
13. Why do you think it is more likely to be adopted?
14. Some railroads have recently considered removing the conductor from the locomotive cab and allowing an engineer to drive alone (with PTC oversight). A few conductors would still be operating from vehicles spread throughout the territory to respond to any train needing conductor assistance. What do you think would be the operational impacts of this kind of operational configuration?

The participants were given one month to respond and received weekly reminders. The participants could save their partial responses and return to the survey at any time before submitting.

After feedback from the participants and to improve the response rate, the questions in Round 2 of the survey featured more guided questions, asking the participants to use traditional Likert scales to rate various items. The respondents were encouraged to add comments to explain each rating. This format in Round 2 was conducive to providing responses from Round 1 anonymously, as those responses formed the basis for the question designs as well as the items to be rated.

SURVEY RESULTS

Round 1 contained seven respondents (three GE and four railroad), and Round 2 contained eight respondents (three GE and five railroad). Since the respondents were from GE and the railroads, there was a wide range of backgrounds and experience as an engineer, conductor, dispatcher, or road foreman. Table 1 presents the mean number of years of experience and range in various train crew member positions the railroad respondents reported in Round 1 of the survey. The respondents' current positions ranged from design and systems engineers at GE, to senior managers and directors of operations, locomotive productivity, operating technology, and safety in Class I railroads.

In addition to the varying levels of experience as an engineer, conductor, dispatcher, or road foreman, the participants had varying levels of experience with different levels of automation systems. The automation systems the participants listed included energy management systems (e.g., GE's Trip Optimizer or New York Air Brake's LEADER), PTC, and distributed power.

The responses from both rounds of the survey offer significant insight into industry views on automation system use and implementation. The results are organized into three sections. First, the discussion will focus on automation features suggested by the participants and their suggested measures of the success of an automation system. Responses from Round 2 on these questions offer a more detailed look at the topics and help validate the Round 1 responses. Second, the survey questions related to variations of a remote crew configuration in freight rail will be discussed. Third, participants' concerns in developing and implementing a new automation system or new configuration of crew roles will be addressed.

Automation Features and Measures of Success

One of the questions in Round 1 asked the respondents to list, in an open-ended format, desired features of future rail automation technology. The suggestions generally fell into three main categories. The following is a condensed list, in no particular order, of several of the automation features mentioned in the survey responses, many of which were mentioned by more than one survey participant.

TABLE 1 Experience Levels of the Railroad Survey Participants

Experience as Crew Member	Mean (years)	Range (years)
Engineer	12.8	0–25
Conductor	13.8	2–31
Dispatcher	0	0
Foreman	8	0–18

Locomotive and Track Health Features

- Ability to autocommunicate fuel levels and distance to the next fueling station,
- Ability to minimize wear on equipment and track infrastructure,
- Ability to perform train inspections remotely, and
- Ability to reduce in-train coupler forces (i.e., improve train handling performance).

Train Movement and Pacing Features

- Ability to reduce train separations,
- Ability to improve rail efficiency and fuel consumption,
- Ability to adhere to maximum permissible speeds and limits of authority, and
- Ability to remove or add slow orders and work zones en route.

Increased Situation Awareness and Vigilance Features

- Speed and train handling alerts;
- Train health and state information;
- Track authority, routing, and switching information; and
- In-cab signaling.

In Round 2, all the features suggested in Round 1 were listed, and the respondents were asked to rate the importance of each feature on a five-point Likert scale, from "not important at all" to "very important." The top three most important automation features, based on average ratings, were the following:

1. Ability to interact properly with disturbances such as slow orders, work zones, and current conditions;
2. Automatic pacing of trains to avoid restricted signals and meet schedules; and
3. Ability to display paperwork and switching, routing, and other information electronically in the cab.

The automation feature that was rated, on average, as the least important was the ability to reduce wear or impact on equipment and track infrastructure. Because of the small sample size, no statistical significance tests were performed; average rankings are used for discussion. Figure 1 shows the average ranking for all the features listed in the Round 2 questions.

Both rounds of the survey asked how to measure the success of future rail automation systems. Again, Round 1 asked the question in an open-ended format. Then in Round 2, each measure of success provided in Round 1 was listed, and the participants were asked to rate the importance of each on a five-point scale (Figure 2). The responses in Round 1 most frequently cited the safety and ease of use of the new system as good measures of success. Other responses included efficiency in time and fuel consumption, how much human intervention is required, compatibility with existing systems like PTC, and reduction in track authority violations. These responses were validated in the Round 2 responses, where participants identified the following three measures of success as being the most important in a future automation system:

1. Train safety,
2. Minimized authority violations, and
3. Ease of use.

The measure of success that received the lowest average rating in Round 2 was that future automation systems would minimize human intervention. Because there were significantly varying opinions on the desire for minimal human intervention, one open-ended question in Round 2 asked participants to describe what "minimal human intervention" means to them. One respondent

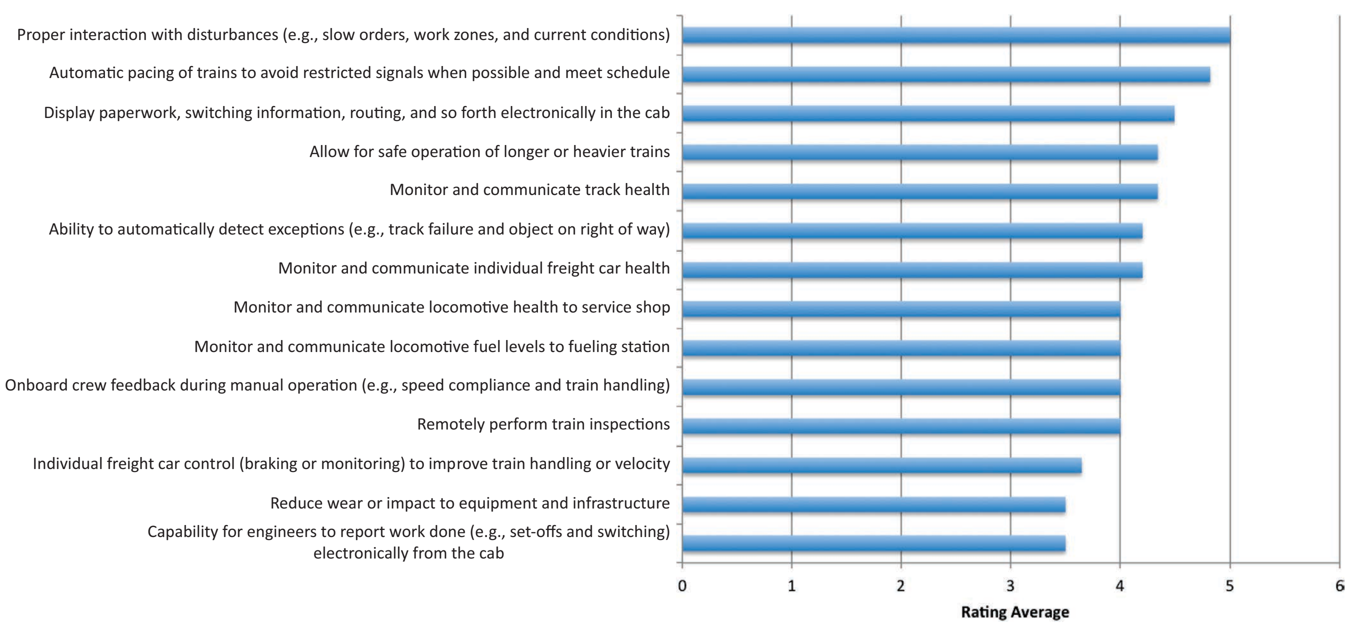

FIGURE 1 Participants' average rating of the importance of each desired feature of a future automation system (Round 1).

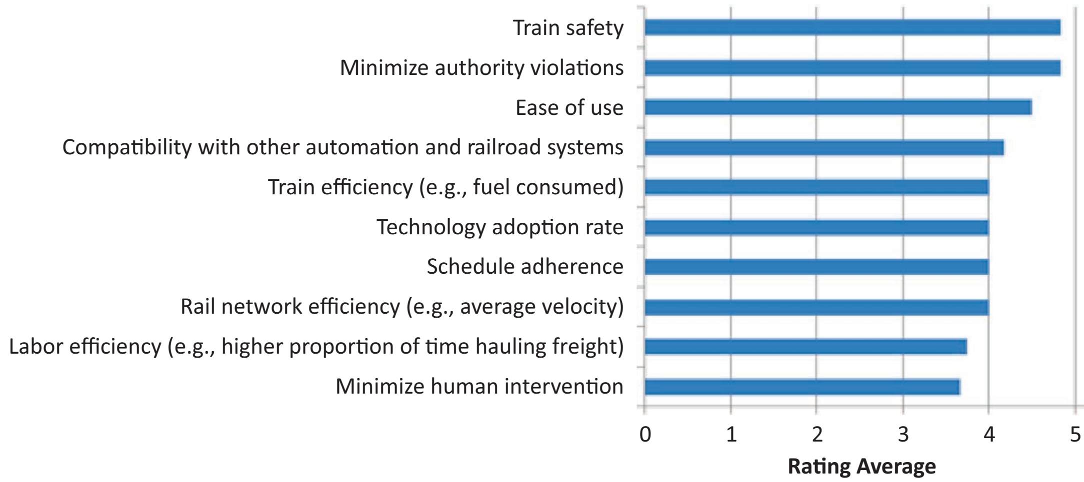

FIGURE 2 Participants' average rating of the importance of measures of success (Round 1).

indicated that this meant that the "human is only there to get the system into a proper setup and fix things when they break." A second respondent wrote that minimal human intervention would be the case where "automated trains can run across their designated route without input or adjustment from operators." This response includes operators on the train and those possibly working remotely. In addition, "humans would only intervene when exceptional circumstances occur which are outside the scope of design of the automated systems." It seems that the participants viewed minimal human intervention as corresponding to the case of a very high level of automation in which nearly all tasks would be covered by the automation system.

In addition to asking for a rating of each of these measures of success, the survey question asked for suggestions on the ways these might be reliably and accurately measured. Table 2 lists all the responses gathered on this question. Many existing measures were suggested as adequate moving forward.

Remote Crew and Crew Member Roles

Several questions in Round 1 of the Delphi survey asked respondents to consider an operational scenario in which the traditional roles of the train crew and the automation systems were redesigned so that a portion of the crew was located remotely. Although not located on the locomotive, this remote crew would still be connected by a communication infrastructure. Although the FRA has since proposed regulation that would require two persons to be assigned to each train, this operational scenario was prompted by one railroad's earlier proposal to eliminate the conductor from the cab and have remote crew members drive to various locations to help with tasks when needed.

The survey asked the respondents to think of functions or tasks that could be performed effectively by remote crew members. In addition, the survey asked the respondents to consider which tasks should be retained by the local crew members in the locomotive. Table 3 shows the list of functions given for these two survey questions.

From the list of tasks and functions, the respondents generally agreed that a train's speed and movement on the track can be controlled remotely. However, in emergency situations that require manual control or an action that automation does not normally perform, it is best to have a crew member onboard the locomotive directly. Several respondents also pointed out that switching activities are tasks that should be retained by the local crew on the locomotive.

The respondents voiced concerns about the configuration of the remote crew. Two participants brought up issues with public acceptance and the need for proper regulations. Job loss was also a concern about reducing the number of people in the locomotive cab. In addition, some respondents commented that a remote crew configuration with associated automation systems would certainly have to be proven reliable and efficient for there to be a chance of acceptance by the industry. Despite these concerns, the respondents acknowledged that there are potential benefits to the remote crew configuration. The primary benefit of a remote crew that would likely reduce the number of people in the locomotive cab would be the ability to have fewer scheduling conflicts. This would lead to better work–rest patterns and predictable schedules for the crew. Safety improvements and cost savings were also mentioned.

The final question in Round 1 that dealt with the configuration of the remote crew asked the respondents to consider what additional automation functions would be required for safe operation in this configuration of roles. Although the question was not meant to lead the respondents to think of a fully automated train with no crew members onboard, the responses leaned toward features that would make a train fully automated. The automation functions included the following:

- Ability to start and stop the train safely,
- Automatic pacing of trains for executing priority movement through a network,
- Forward-facing cameras on the locomotives and cameras or sensors on the tracks for real-time surrounding vigilance, and
- Ability to secure an unmanned train.

A related question in Round 2 of the survey listed functions that a locomotive crew must perform and asked the respondents to rate the opportunity or benefit from increased automation for each function. These functions were derived from an abstraction hierarchy that was developed in parallel (*14*). Including the functions here with

TABLE 2 Respondents' Suggestions on Accurately and Reliably Measuring Success

Measure of Success	Suggestions on Reliable and Accurate Measurements
Train efficiency	Develop ideal consumption for subdivision and measure improvement or decrement once system is introduced Use existing fuel efficiency reward program data Measure gallons per GTM
Rail network efficiency	Measure the same way velocity is measured now
Labor efficiency	Record train delays and dwell times Number of employees per GTM, number of remote operators per GTM, crew cost per GTM, unproductive crew cost per GTM (declining with automation)
Ease of use	User surveys that measure against traditional operation scenario where there is no PTC or energy management versus systems that are being studied; include open-ended questions at the end for areas of improvement Operator input, directly from crews Training time for remote operator and length of learning time for all involved
Train safety	Set up risk matrix that looks at exposure to hazards, likelihood of outcome and outcome; each system will have an effect on an exposure and can be measured; maybe use the Delphi method to populate matrix and arrive at relative risk Incident rate Number of accidents and incidents; FRA–National Transportation Safety Board of Canada accident ratio versus nonautomated trains Number of near misses; number of train separations/broken knuckles and drawbars due to train handling or excess in-train force; number of derailments; number of crossing accidents/trespasser incidents where automation system is a factor
Compatibility	Check for errors and delays between systems or within system; set up primary and secondary task relationship within simulator; add in locomotive systems and read time to search for objects, time to actuate systems, etc. Record number or percentage of trains which cannot run automated due to incompatibility; added crew costs due to trains which cannot run automated due to incompatibility; delays to trains and/or added dwell time to traffic due to incompatibility Measure number of features not compatible
Minimize human intervention	Compare to traditional operation without PTC and energy management Miles spent in automatic mode versus manual mode Record number of intervention events, ratio of remote operators to trains running or train miles achieved Number of touches or interventions
Schedule adherence	Measure train plan variance Look to the way schedule adherence is measured now
Minimize authority violations	Discipline history Number of authority violations Number of trains that went past a red light
Technology adoption rate	Compliance reports Number of automated trains versus nonautomated trains on network Number of automated GTMs versus nonautomated GTMs Number of trains using automatic and percentage of time spent in automatic

NOTE: GTM = gross ton miles.

TABLE 3 Suggested Tasks to Be Performed by Remote and Local Crews

Tasks Performed by Remote Crew	Tasks Retained by Local Crew
Handle train movements through territory Train inspections Track inspections Remotely operating train on main line with no en route switching; operating more than one train Pullback of tracks in yard switching Monitor signals Air brake application Speed control Alert button application Monitor train location	Exceptions requiring manual interventions (i.e., automatic switch failure, other mechanical failures) Switching activities, coupling, and uncoupling Assembly–disassembly of trains Guidance over unprotected public crossings Horn and bell operation Monitoring environment for emergency situations Air brake application Monitoring gauges Checking that siding is clear

a comment box allowing respondents to refute or add to the list of functions served as a partial validation of the abstraction hierarchy. The three functions that the respondents thought would benefit the most from increased automation were the following:

1. Maintain awareness of and respond to current track conditions (e.g., adhesion-braking capability),
2. Maintain awareness of and incorporate new information received en route (e.g., slow orders), and
3. Maintain awareness of and respond to maximum safe speed.

In general, it seems that the respondents considered automation functions that improved real-time situation awareness to be more important than functions that looked ahead and assisted in developing a long-term plan. Further, one participant thought that almost all automation had no benefit or was even potentially harmful. The idea of increasing automation to help with crew tasks is not universally accepted. Figure 3 shows how participants ranked the benefit of increased automation for all the listed locomotive crew functions.

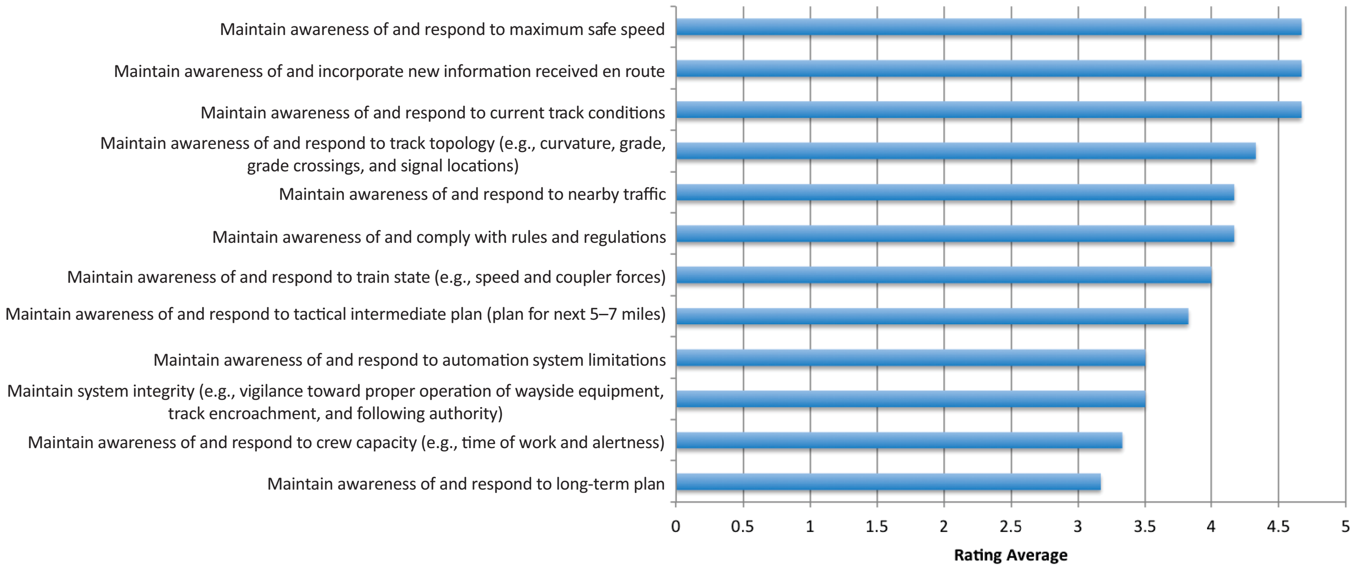

FIGURE 3 Rating averages of participants' opinions about the opportunity or benefit from increased automation for each locomotive crew function (Round 2).

Automation Concerns and Suggested Solutions

Technological advancement and increased automation in the rail industry elicit a broad range of responses. Many people acknowledge the benefits and potential safety gains of automation, but others resist change and raise valid concerns. Questions in both rounds of the survey asked participants to enumerate some of their concerns about increasing automation in the cab.

The following is the list of concerns that respondents raised in Round 1 of the survey about increasing amounts of rail automation technology:

- Automation products tend to be sold before they are developed and the customer has to wait an extended period for production.
- Reliance on automation technology makes it more difficult for engineers to operate in manual mode when required. (The deskilling of engineers is a concern.)
- Train crews may become so tied up or engaged with monitoring or manipulating the technology that they fail to look out the window and pay attention to the other things for which they are responsible.
- Training crews should be balanced thoroughly with the technology, with efficiency and time effectiveness.
- Automation systems do not perform as promised.
- There may be incompatibility of multiple automation systems.
- Because of potential deskilling, layers of safety overlays must be in place to ensure safety when technology fails. These safety layers can have the effect of reducing network velocity and throughput because they are always implemented in a conservative way. The increased productivity from automation must outweigh the reduced productivity from safety systems.
- The cost of automation implementation is high.
- There would be loss of jobs.

The possible deskilling of train crews because of the increased use of automation was the most-cited concern of the respondents in the Round 1 question. In Round 2, the respondents were asked to rate possible solutions to this problem. The results of this survey question are shown in Figure 4. The solution with the highest average rating, the one most likely to reduce operator deskilling and its effects, was to improve the design of transitions from automation to manual modes, to improve operator awareness.

The respondents expanded on their concerns with some aspects of technology implementation in another question in Round 1 of the survey. This question asked the participants to describe their previous experience with the introduction of rail automation technology. Two main issues emerged. The first issue that emerged was that respondents commented on the development process of automation products. There is a belief that "designers of the technology are too far removed from the train crews' environment." This distance results in products that do not perform as expected, "systems that do things we don't need . . . or cause complications and delays to other phases of the operation." Ultimately, this disconnect during the development of new automation technology prevents overall acceptance and use of the products when automation is implemented. The second issue that emerged was that of operator training. The respondents commented that proper training on new automation systems—in the classroom, simulators, and on-the-job training—could help operators use the technology to its full potential. Crews are often resistant to change and new technology, but training is one way to promote operator acceptance.

Both issues were addressed in Round 2 of the survey, by asking the respondents to rate possible improvements and solutions to the problem of technology development and training. The survey participants were in agreement that the following suggestions (listed in order of average rating) might improve the way new automation technologies are developed:

1. Have railroad personnel participate in early concept design reviews;
2. Have the railroad provide opportunities for design engineers to gain operational field experiences; and
3. Encourage developers to employ former railroaders in design, testing, and evaluation positions.

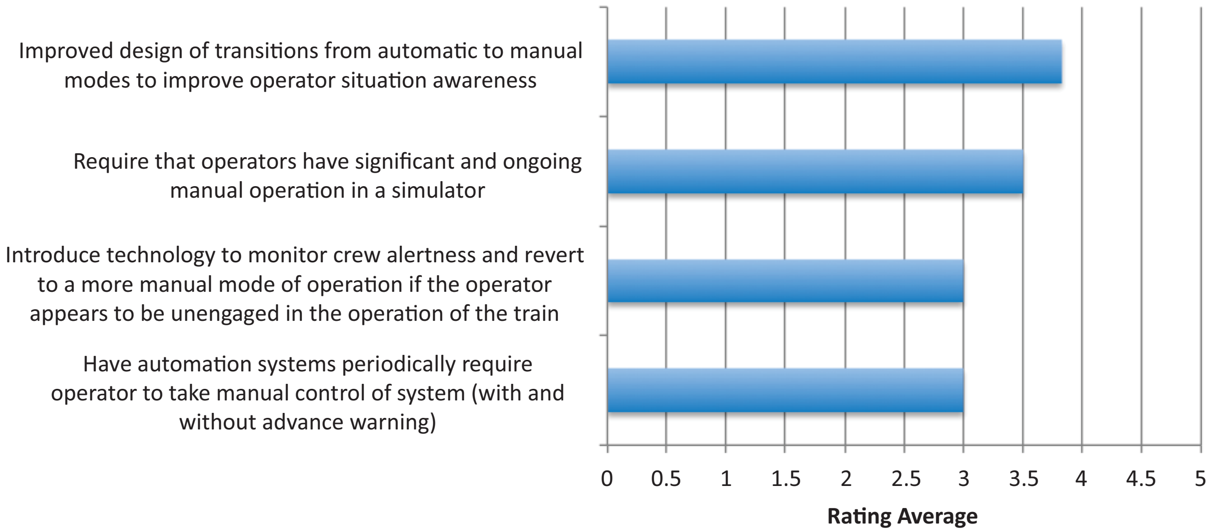

FIGURE 4 Rating averages of possible solutions to reduce operator deskilling (Round 2).

The rating averages for all the suggestions are shown in Figure 5. Although the participants thought the three listed suggestions could improve the situation, they were also in agreement on one suggestion that is very unlikely to work in the real world. The suggestion was to have railroads create a technology fund for the initial development of automation and then receive discounts on the resulting products. When asked to give a reason for their rating choice, two respondents commented that "railroads are notorious for not agreeing on anything," so requiring railroads to invest money in jointly funding projects would be unlikely to work. Railroads are also skeptical about investing money without a "guaranteed return in a solid product at a solid delivery date." Involving the railroads in early technology development is one suggestion to change the displeasure with the current process, but it requires far more cooperation between stakeholders, which may not be viable at this time.

The responses in Round 1 indicated that training should be improved to set operator expectations, improve operator acceptance, and build appropriate levels of trust in automation systems. To obtain more details on this issue, one question in Round 2 asked respondents to rate possible solutions by their likelihood to improve training effectiveness. Three solutions emerged as the most likely:

1. Provide operators with additional simulator time;
2. In the current classroom environment, present examples of failure caused by human overreliance on automation and the business impact of underutilizing automation; and
3. In the current classroom environment, provide examples of designed strategies for the automation system, and discuss and explain the differences from typical operator behavior in common scenarios.

The fourth rated solution was to incorporate more on-the-job training. However, the solution that survey participants thought was least likely to improve training effectiveness was to incorporate additions to the automation system interface explaining the behavior

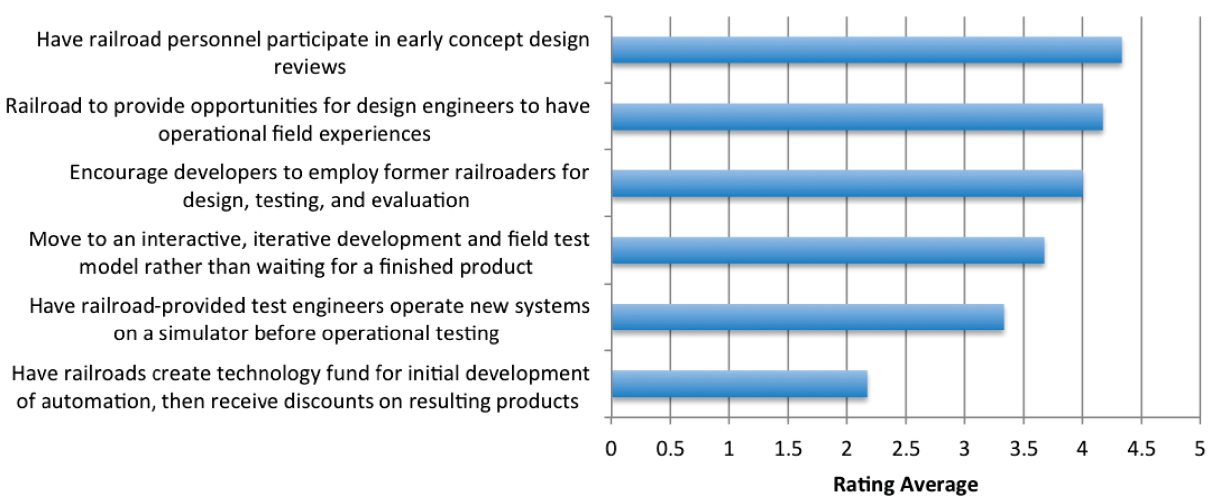

FIGURE 5 Rating averages of participants' opinions about the likelihood of each solution for improving the way automation products are developed (Round 1).

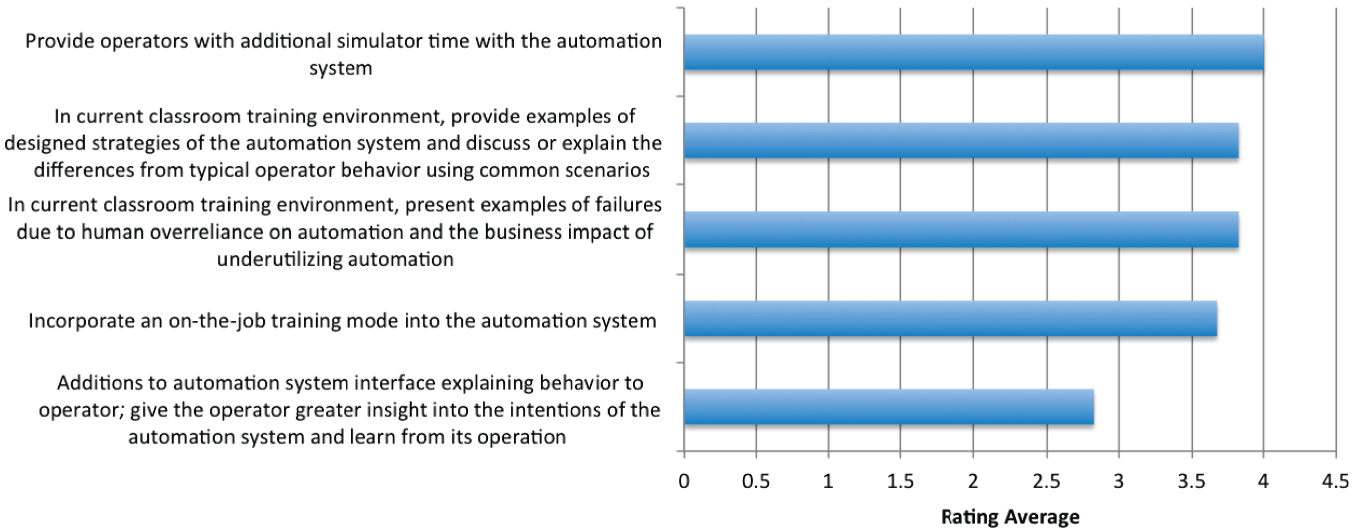

FIGURE 6 Rating averages of possible solutions to improve training (Round 2).

to the operator. This practice is intended to allow the operator to have greater insight into the intentions of the automation system and learn from its operation. Based on the average rating, participants were unsure that this suggestion would improve the effectiveness of training. The full results are given in Figure 6.

CONCLUSIONS AND FUTURE WORK

The industry seems generally to want additional automation and is open to concomitant changes in operating configuration. All the desired future features (Figure 1) and functions that would benefit from increased automation (Figure 3) received an average positive rating. The areas of future technology that were seen as the most important relate to an awareness of changes in the external environment and reacting accordingly.

The idea of a remote crew member received mixed reactions. Views were also mixed about which tasks should remain in the domain of a physically located crew member. It was generally found that local crew members would need to continue to deal with exceptional situations and safety-critical controls and monitoring. General monitoring and straightforward train movement were broadly seen as tasks that could be performed remotely.

Although many existing measures of system performance seem to be appropriate going forward, there is clearly an opportunity for defining new metrics of automation system performance and acceptance. In particular, the respondents suggested looking more critically at training effectiveness and reporting of various near misses. Systems compatibility is another performance requirement for which there are no good established measures. There is also a gap in understanding how often interactions with various automation systems are required.

There is an opportunity to develop new development processes in which controls and system designers and industry experts cooperate. However, it seems that there is significant concern that the industry will be unable to fund the development of new technology, potentially preventing the desired early collaboration between designers and experts. Finally, although this work provides a management and developer view of future automation technology, it would be instructive to conduct a larger-scale survey of the attitudes toward automation held by the conductors and engineers who work with these systems daily. Although managers are often former engineers, current engineers, who must interact with current automated systems on a daily basis, may have very different opinions about interaction and issues of deskilling and training, since their livelihoods are directly impacted. Similar studies have been conducted in the aviation domain (*15–17*).

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