User-centered development of a train driving simulator for education and training

Birgitta Thorslund[1], Tomas Rosberg, Anders Lindström, Björn Peters
The Swedish National Road and Transport Research Institute (VTI)
581 95 Linköping
[1]Telephone: Int +46 13 20 41 55
E-mail: {birgitta.thorslund|tomas.rosberg|anders.lindstrom}@vti.se

Abstract
A user-centered, agile approach was used to develop a high-standard train simulator for applications in train driver education. Thus, a user group of train operators and train driver educators was formed to share experience and development cost. Joint prioritisation by the user group was used in combination with agile development to iteratively develop new versions of the train simulator, responding to the user group's demands. The user group has grown from 2 organisations in 2015 to 10 organisations in 2019, each of which now use the train simulator in education and training. This approach has been beneficial not only in terms of quality, cost and time. But also, as a response to a highly competitive and fragmented market. Early on in the process, the user group requested process results from applied research. This is well in line with VTI's objectives, and three PhD projects have already started and several other projects on driver behaviour, railway signalling systems and capacity have been initiated.

Keywords
Train driving simulator, User-centered development, Agile development, Simulation-based training, Railway safety systems, Railway signalling systems

1. Introduction

Railways provide one of the safest modes of travel and transport available today. Maintaining a high level of traffic safety in the railway system depends directly on the possibility to educate and train staff to understand and make proper use of the technical and procedural knowledge associated with the train protection system (e.g. ATC, STM, ETCS, ERTMS). These systems are implemented both as technical solutions in signalling systems, in rules and regulations, as well-documented organisational roles that help assign and maintain responsibilities, and as established best practices for handling exceptional situations. The demands on train drivers for competence in these areas are high, as well as on personal qualities such as being responsive, yet meticulous and stress-resistant.

In Sweden, the educational paradigm for train drivers has traditionally been predominantly theoretical, for two main reasons: The first reason is the safety aspect, which prohibits practicing on track in real trains until the train driver candidate has achieved a relatively high level of theoretical proficiency, and even then, only under strict supervision. The second reason is lack of educators and train driver supervisors, which is a strongly limiting factor in train driver education and training (Svenska Byggbranschens Utvecklingsfond, 2018). And even if on-track training with skilled supervisors was – hypothetically an option, many critical situations occur quite rarely in real life. Furthermore,

on-track training provides less controllable training with respect to training curriculum.

The factors mentioned above makes on-track training and experience build-up a relatively slow, inefficient and hard to control approach. At the same time, many of these critical situations require accurate, timely and often immediate action, and their handling therefore needs to be well-rehearsed. Furthermore, the working situation for train drivers is special, since a long period of very limited cognitive load, requiring endurance, can suddenly be replaced by an extremely stressful situation. Such events put high demands on attention, responsiveness, and problem-solving capabilities, and yet must not lead to a loss of focus on safety and procedural correctness. Therefore, a combination of theory and targeted practice of specific situations could potentially improve the effectiveness, quality and efficiency of train driver education. Handling of critical situations could be trained before they occur and save both lives and financial resources.

Driving simulators offer ample opportunity for this type of efficient and relevant, targeted training. They can be used to provide training scenarios featuring both the interactivity, complexity, and simultaneous use of different domains required not only to train novice drivers, but also to train or refresh the skills of older drivers (Lees, Cosman, Lee, Rizzo, & Fricke, 2010; Casutt, Theill, Martin, Keller, & Jäncke, 2014; Pollatsek, Vlakveld, Kappe, Pradhan, & Fisher, 2011). Train driver educators in Sweden have recently started to recognise the benefits of using train simulators in education. The pedagogical advantages with simulator-based training are many, including the possibility to layer theory and practice (Hedman, 2017). In aviation, pilot training in simulators has been common practice for many decades, and simulator-based training is also common in maritime and naval education. Although there are several commercially available train simulators on the international scene, they have not to date been considered a viable option for Swedish actors. This is because they do not include Swedish railway sections, and another reason is that they are based on proprietary, closed software, making joint development and research approaches more difficult. Furthermore, the cost of these commercially available solutions is typically not within the budget frame, neither of national Swedish train driver educators, nor of train operators who typically would rather be in need of a larger quantity of low-cost simulators. National Swedish educators and train operators share the view that in order to allow for as many drivers as possible to be able to use the train simulator for practice, it is important to keep the costs down.

The Swedish National Road and Transport Research Institute (VTI) has more than 40 years' experience in using simulators and is a leading authority in conducting simulator experiments and developing simulator methodology and technology (Thorslund, 2013) primarily targeting road traffic. For some reason, it has been more difficult to get funding for research on rail traffic. Since 2015, a scheme for development of train simulators, based on the same proprietary simulator software and with existing Swedish tracks represented, has been successfully developed, based on user involvement and needs, with a main application in train driver education. During this process, agile methods (Agile Alliance, 2018) and user-centered systems design (UCSD) (Norman, 1986) have been employed, and this contribution describes this development process as a case study and summarises the benefits of joint collaborative development of train simulators in this fashion, which is unique.

2. Objective

There are two general aims of this work. The first aim is to explore a method to continue the development of VTI's train simulators, using UCSD. This should enable cost-effective

and efficient simulator-based driver training on actual Swedish tracks, as a complement to the traditional approach of real-world practice combined with theoretical studies. Specifically, the initial users (train education academies and operators) of the train simulators had expressed the need for rather specific use cases, in the form of implemented driving scenarios on actual Swedish tracks, for individual training. Such scenarios require substantial amounts of software development and would consequently be quite difficult for each user to fund individually. To the concepts of UCSD and agile development was therefore added a third component to the development scheme, namely the idea to share both costs and knowledge between users. The second aim is to create a platform for performing research on driving behaviour from a traffic safety, efficiency and capacity perspective.

The research questions to be answered are:

1. How well does this scheme for joint, agile, user-centered development work with regard to
    a. developing train simulators, and,
    b. carrying out research on driving behaviour?
2. What are the main beneficial outcomes or results from this scheme, and who benefits from these results?

3. Method

The project described here is unique in that it brings together competitors on a de-regulated market in a user-centered collaborative scheme, with the goal of jointly developing a realistic, validated educative simulator tool, to improve traffic safety for all parties involved, and ultimately for the benefit of society. To this end, a user forum was created by inviting train operators and train staf educators, operating in Sweden. They were enrolled in a formally arranged user group, called "TUFFA" ("Tågsimulatorutvecklingsforum för användare" i.e. "Train simulator user development forum", in translation). To join, a pre-requisite was that each member acquires a train simulator from VTI, at a nominal cost of approximately € 15,000 – 25,000, dependent on physical configuration. This is necessary to be able to share knowledge, experience and requests for development. An annual membership fee of € 10,000 was also compulsory. Regular meetings were arranged to generate and prioritise short lists, governing the software development to be carried out by VTI for the joint fees obtained. All development results and updates were shared among the members of TUFFA by digital distribution (via an FTP server), keeping individual costs down.

Two methods are used to answer the research questions. Question 1a) is answered by observing how the TUFFA initiative has proceeded and what joint prioritisations and results the UCSB approach has achieved. Question 1b) is answered by making an inventory of the research projects initiated as a result of the TUFFA initiative. Question 2 is answered through a survey among the TUFFA user group.

3.1 UCSB approach

The user group meet twice per year at each other's sites. These are very similar as can be seen in Figure 1. The first companies to join the user group were train driver academies and they invested in passenger train simulators, like the one at VTI. Freight train operators waited for the freight train model to be established, which was performed during 2016 (Andersson, Lidström, Peters, Rosberg, & Thorslund, 2017). During the user meetings, knowledge is shared, and decisions are made on which developments that should be made.

Examples of shared knowledge is special scenarios and ideas on how to structure test protocols.

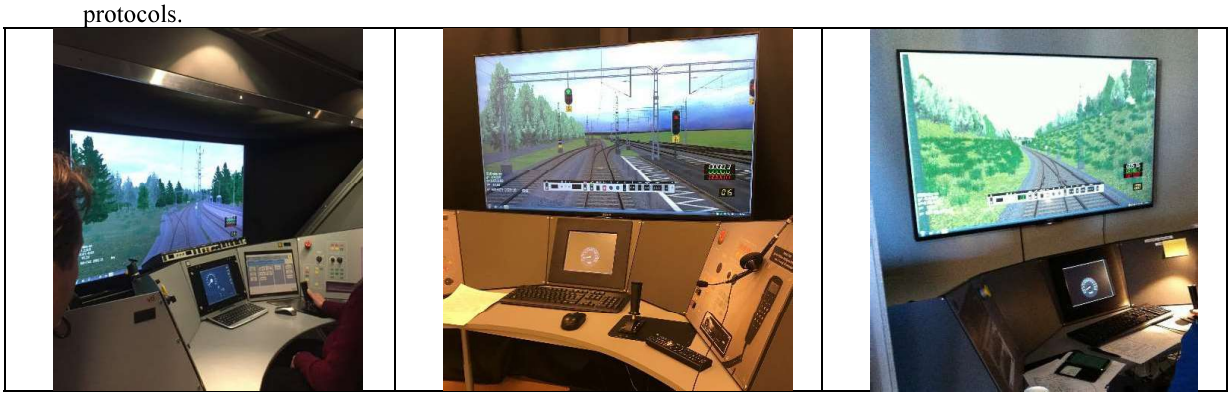

Figure 1 User meeting at 3 different sites. From the left; VTI, Nässjöakademin, and TCC.

The multi user centred design in the user group is described in Figure 2. The main developing loop is driven by the TUFFA member group and has a 6-month cycle time from setting requirements and needs to delivery to train simulation code base. However, parallel with this activity there can be several UCSD processes driven by special customer needs. These activities have in general a shorter cycle time.

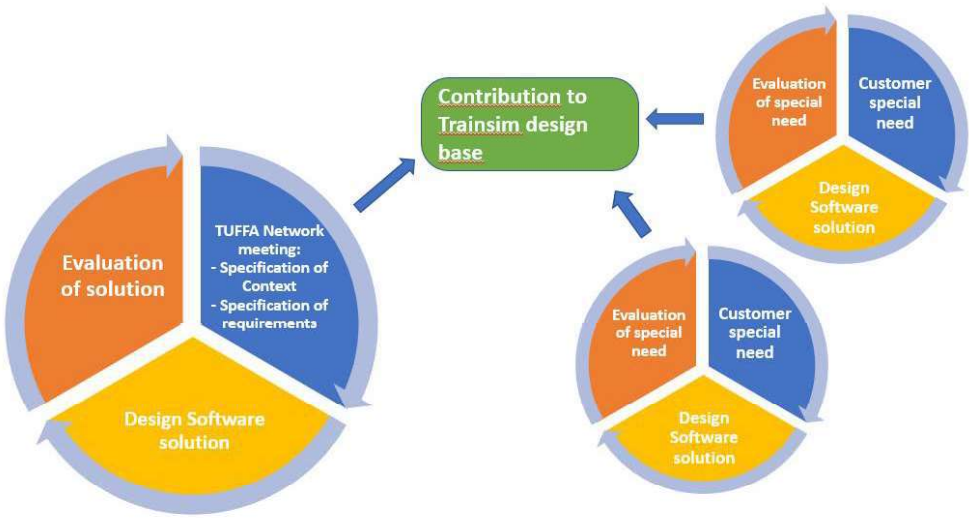

Figure 2: Multi user design development in the TUFFA train simulation network.

The train simulation software has been developed based on the 12 principles behind the Agile manifesto (Agile Alliance, 2018). For the present type of project, an agile way of working was judged to be particularly suitable. In contrast to the traditional plan-based or "waterfall" way of managing projects, the agile methodology is more suitable when the

requirements are not all well-defined beforehand, and when creativity and innovation and maximizing the value of the resulting software is top priority. A prerequisite, though, is that work must be possible to organize into iterative, short development cycles, each resulting in step-wise deliverables, that can be successively evaluated and further developed. In development of VTIs train simulators, the close contact between software developers and train educators, continuous dialogue and mutual feedback has been essential for developing a successful product and ensuring its validation. Important for VTI has been to meet the ideas, changes and deliverables from the members. Requirements have been set from VTI on the customer specific projects. New functions shall not prevent other members to use the software in the way it was intended. On the opposite, these customer specific contributions should benefit all members in the group. This has also proved a successful way to promote collaboration between competitors.

Table 1 Twelve principles of the Agile manifesto (Agile Alliance, 2018):

12 principles of the Agile manifesto:
1. Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.
2. Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.
3. Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.
4.Business people and developers must work together daily throughout the project.
5. Build projects around motivated individuals. Give them the environment and support they need and trust them to get the job done.
6. The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.
7. Working software is the primary measure of progress.
8. Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.
9. Continuous attention to technical excellence and good design enhances agility.
10. Simplicity--the art of maximizing the amount of work not done – is essential.
11. The best architectures, requirements, and designs emerge from self-organizing teams.
12. At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.

3.2 Research initiatives

With VTI being a research institute in the field of transportation, the main interest is to perform transport related research. Together with the user group, relevant research projects have been formulated and applications for funding have been made also in collaboration with other partners. Several areas of interest were identified within training, capacity and energy efficiency:

- Evaluation of the in-train practical training, concerning what is trained, since fortunately difficult situations do not appear very often. However, when they appear it is important that the driver knows what to do.
- The shift to ERTMS and the effects on driving behaviour, capacity and energy efficiency.
- Exploring the possibilities to use train driving simulators to create realistic co-driver scenarios for train management students.
- Creating an interface between the train simulator software at VTI and RailML to enable drivability studies of infrastructure design and speed limits.
- Connecting existing tools for train simulations to include driving behaviour in train scheduling and capacity planning.

3.3 User survey

At a user meeting in Gothenburg, the members were asked to fill in a short survey with questions covering their experiences from the simulator and requests for the future. The questionnaire is translated into English and included in Appendix 1. A short description of the questions including both free text and Likert-type scales (Likert, 1932) follows:

The respondents represented either train operators, train educators or both and stated this as background information. They were asked to describe what they use the simulator for. The facilitation following the opportunity of using the simulator in the education was rated on a scale (from 0 = not at all to 4 = very much). The most important application was described as well as the feature thought to be most important to develop. The time of which the respondents have worked with the simulator was stated and the number of people educated or trained by it. The respondents were also asked if they save time or money with the simulator and in that case how much. If they can train specific situations, other than without the simulator, and in that case which, was also asked. Finally, the respondents rated on a scale (from 0 = no good at all to 4 = very good), how they feel about the concept of sharing resources and being part of developing the simulators.

4. Results

4.1 UCSB approach

The TUFFA user group, formed in 2015, initially consisted of two train driver educators, who primarily focused on passenger train simulators. Freight train operators joined the group once a freight train simulator model was developed in 2016. As of October, 2018, the group consists of 9 members, and a tenth is going to join in 2019. Bi-annual meetings, hosted by alternating members of the group, were used for short-listing and prioritising the desired development, which was then implemented by VTI, and the resulting software and models made available to all members, following these 6-month cycles. As a result, 4 different types of simulators are now available, all based on actual Swedish rail data, each being subjectively regarded to be of high international standard, after being validated in use by a large number of train drivers and students. The development cost for this is estimated to have been in the order of 1/10 of a hypothetical (non-existent), alternative commercial solution. Based on requests from the TUFFA user group, the common simulator software has been made available in several different physical configurations, ranging from a generic laptop PC version equipped with one or two control levers (accelerator and brake), to

authentically mimicking real driving environments a “Regina” passenger train, and one featuring a Traxx™ control panel for freight trains. Figure 3 and Figure 4 show examples of the developments requested by the users during the first two years.

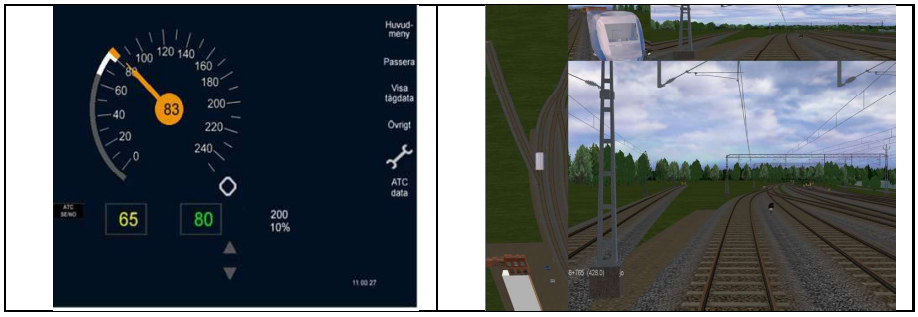

Figure 3: Example of development accomplished during the first year, STM and scenario replay (feedback)

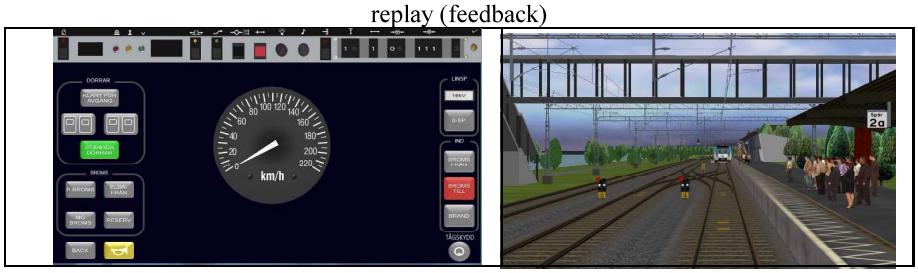

Figure 4: Example of development accomplished during the second year, DMI screen from a customer project and a shunting scenario in Jönköping.

4.2 Research initiatives

As a direct result of the requests by TUFFA users, four research projects have been formulated (and are either nationally funded or about to become funded), based on problem formulations emanating directly from the group’s needs. Three PhD projects have recently started at VTI, all of which are based on ideas generated within the TUFFA group. One thesis focus on driving behaviour studies with the ERTMS signalling system, and capacity modelling. The second PhD student will study driving models in relation to ERTMS, and the third thesis deals with pedagogical aspects of simulator-based train driver education.

4.3 User survey

The members of TUFFA all describe how collecting and sharing experiences within the group has been of great value. A survey was conducted with 8 users (3 operators, 4 educators, and 1 who is both). The survey showed the following results:

- The simulator is reportedly used for
  - introduction and training of special scenarios
  - train control systems (ATC/STM/ERTMS)
  - to transfer theoretical knowledge into practical skills
- The simulator facilitates the training or education significantly

- The most important areas are
    - training before the first practice
    - repetition of difficult cases
    - training of rarely occurring situations
    - training of special traffic safety scenarios

One respondent, a train driver educator, explicitly stated that they gain approximately 25% in time. Two train operators mentioned an (unquantified) economic gain, while another reported the gain to be in terms of quality. All 8 respondents report that they now train situations, using the simulator, that were not possible before, including "preparations before practical training, stop signals, special scenarios, ERTMS driving", and "help vehicle". This also makes the learner drivers better prepared for the on-track training.The TUFFA collaboration concept is top rated (4 out of 4) by all respondents but one, who rates it as 3 out of 4.

5. Discussion

The aims of the reported study were to explore a method to continue the development of the train simulators, using UCSD, and to create a platform for performing research on driving behaviour, from a traffic safety, efficiency and capacity perspective. The research questions are discussed one by one and followed by a method discussion.

Three years of collaboration has led to several improvements and large development steps for the simulator, in line with the user requests. This is evidence for a suitable and fruitful approach concerning development in this context. Furthermore, several research projects have received funding and are initiated together with the users, reveals that the users, although competitors in some way, have the same problems and interest in solving these together. There are many important research topics to be investigated and research is also something that the members request. They wish to learn and understand more about driver behaviour, attention and energy efficient driving for example. Fortunately, the research requested is in line with previous studies of driver behaviour and driver training conducted at VTI (Abadir Guirgis, Peters, & Lidström, 2013; Abadir Guirgis & Peters, 2015). With many members from both train driver educators and operators we will be able to design several interesting studies and collect big data sets.

When it comes to the major beneficial outcomes and for whom, we believe that there are many. With small means we have developed first class train simulators for, training, education and research. With these tools, operators can efficiently educate and train their staff before the shift to ERTMS, which will certainly have an impact on safety, capacity and efficiency. In the train driver education, quality can be improved by the possibility to create situations that are important to be skilled in, however hard to practice. Operators, passengers, and many more will benefit from safe and skilled drivers. Interestingly, most of the users do not believe that they will save neither time nor money by using the train simulators. This is in line with our idea to introduce a complementing tool and not a replacement. We also believe that the quality may be improved by this complement, which was also suggested by the users.

With a wider area of use, enabled by for example developing a Train Management system, possibilities are created to investigate the complete system of train driver, train management and traffic planning. An interface to RailML, will also open for possibilities

drivability studies which can be used for infrastructure planning. These are examples of good beneficial outcomes for the Swedish road administration.

Consistent with Norman, the needs of the interface have dominated the design in the newest portable version of the train simulator developed in collaboration with one of the operators (Norman, 1986). The development has been an iterative process and the involvement of the users has also been very significant (Karat, 1997). Gulliksen and colleagues (Gulliksen, et al., 2003), suggested principles, activity lists and tools for applying UCSD. This collaboration project has used several of the twelve principles of the Agile manifesto (Agile Alliance, 2018). The motive was purely that it seemed like the most reasonable way forward for a stepwise development in which both users and developers expanded the knowledge needed to reach a success goal. But it also required that customers understood the need and benefits of investments of resources in the product development and the need for collaboration despite being competitors. This is a unique approach which turned out applicable to a complicated context.

As mentioned in the introduction, although there are international commercial actors providing train simulators, these solutions do not meet the needs of the users within TUFFA and our research interests. The resulting open source software and the agile development approach used within TUFFA, on the other hand, leads to low costs, custom-tailored solutions for the users, and to the build-up of a sustainable and long-lasting research platform for several types of research on pedagogy, method, safety, capacity, energy-efficiency etc. for us as researchers.

6. Conclusions

In less than three years, a high-standard train simulator which is used for driver training has been developed to become a widely used educational tool, based on user needs. This was done through a user-centered collaborative scheme in the “TUFFA” user group, arranged and organized by VTI, for the benefit of railway traffic safety, but also with the co-purpose of creating a platform for further research into human behaviour. By sharing both experiences and costs for development, competing operators and education actors on the Swedish market are now equipped with train simulators tailored to their collective needs, and which they have put to immediate use in their training and education programmes. They all report how this has been beneficial in terms of quality, cost or time. Also, from a research point of view, this scheme has been very successful, resulting in several funded projects, and in three PhD projects so far. This is a major step forward since the branch needs useful tools to prepare for the shift to ERMTS, and at least in Sweden this would be very difficult to accomplish without this unique collaboration.

References

Abadir Guirgis, G., & Peters, B. (2015). *Simulatorbaserad utbildning i ERTMS-Utvärdering av utbildning och träning för lokförare i VTIs tågsimulator.* Linköping: VTI.

Abadir Guirgis, G., Peters, B., & Lidström, M. (2013). *Lokförarutbilding i Sverige-Simulatoranvändning och ERTMS.* Linköping: VTI.

Agile Alliance. (2018). 12 Principles Behind the Agile Manifesto. Hämtat från www.agilealliance.org

Andersson, A., Lidström, M., Peters, B., Rosberg, T., & Thorslund, B. (2017). *Framtagning av loktågsmodell för VTI:s tågsimulator/Development of a freight train model for the VTI train simulator.* Linköping: VTI.

Casutt, G., Theill, N., Martin, M., Keller, M., & Jäncke, L. (2014). The drive-wise project: driving simulator training increases real driving performance in healthy older drivers. *Front Aging Neurosci, 6*(85), 1663-4365.

Hedman, L.-Å. (2017). *Use of Train simulator in Train driver education.* Nässjö: Nässjöakademin.

Lees, M. N., Cosman, J. D., Lee, J. D., Rizzo, M., & Fricke, N. (2010). Translating cognitive neuroscience to the driver's operational environment: a neuroergonomic approach. *Am J Psychol, 123*(4), 391-411.

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology, 22(140)*, 1-55.

Norman, D. (1986). Cognitive Engineering. i D. Norman, & S. Draper, *User Centered Systems Design.* Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Pollatsek, A., Vlakveld, W., Kappe, B., Pradhan, A. K., & Fisher, D. L. (2011). Driving Simulators as Training and Evaluation Tools: Novice Drivers. i D. L. Fisher, M. Rizzo, J. Caird, & J. D. Lee, *Handbook of Driving Simulation for Engineering, Medicine and Psychology.*

Svenska Byggbranschens Utvecklingsfond. (2018). *Kompetensanalys järnväg i Sverige till 2025.*

Thorslund, B. (2013). Cognitive workload and driving behavior in persons with hearing loss. *Transportation Research Part F: Traffic Psychology and Behaviour, 21*, 113-121.

Appendix 1 Survey on user experiences of the train simulator

1. Do you represent a train operator? ☐			or a train academy? ☐	
2. For what do you use the simulator?				
3. To what extent does the possibility to use the simulator facilitate the education or training?				
Not at all				Very much
☐	☐	☐	☐	☐
4. What is the most important use you think?				
5. What is most important to develop next?				
6. For how long have you been working with train simulators?				
7. How many have you trained with the help of the simulator up to now?	in basic education?		in further education?	
8. Do you save time using the simulator?	Yes ☐		No ☐	
9. If yes, estimate how much (estimate in%)				
10. Do you make a profit by using the simulator?	Yes ☐		No ☐	
11. If yes, estimate how much (estimate in%)				
12. Can you train moments in the simulator that you could not do earlier?	Yes ☐		No ☐	
13. If so, which ones?				
14. What do you think of the TUFFA concept to share costs?				
Not good at all				Very good
☐	☐	☐	☐	☐