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Measuring Attitudes Towards VR Technology Simulation Training of Train Drivers

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This paper presents the results of measurements of attitudes towards a demonstrative virtual-reality railway simulator for eco-driving techniques training. This device has been prepared for InnoTrans 2016 railway trade fair, and during this exhibition 144 railway professionals from 35 countries took part in the simulation and filled a questionnaire about their experience and whether they found this type of simulator a viable choice for railway driver training. The results have been very positive with barely any negative answers. This shows that a VR-based railway simulator could potentially be used as a low-cost solution supporting energy efficient train driving.

Keywords: VR, simulator, eco-driving, eco-innovation, railway.

1. INTRODUCTION

This paper aims to present the results of research into user attitude towards such an eco-innovation created by the REDS SA company from Poland. This innovation is based on using a new technology - virtual reality - to teach train drivers how to drive efficiently and consume less energy while still adhering to the timetable and obeying safety rules. This solution could potentially be used to create realistic training scenarios for drivers without the need to use large-scale simulators which are expensive and require large areas for deployment. A demonstration version of such a virtual reality simulator was presented at the InnoTrans 2016 trade fair in Berlin. Device users were asked to fill a questionnaire about their experience and the results of this survey along with the specifications for the virtual reality simulator are presented in this work. The goal of this research was to find out whether this kind of innovation would be acceptable as a new teaching tool in the railway industry.

2. ECO-DRIVING AS AN EXAMPLE OF ECO-INNOVATION

Eco-innovation is a term that has been rapidly gaining traction in the recent years. Kemp and Pearson [1] define it as an act of introducing something (product, process, service or method) that is new to the organisation and has a positive ecological impact on the company's footprint compared to other, relevant alternatives. Most definitions in the literature [2; 3; 4; 5] are similar and tend to refer to two major consequences of eco-innovations - lower negative impact on the environment and more efficient use of resources. However, there are some differences in the way that eco-innovation is defined by researchers, two main approaches can be distinguished: in the first one attention is focused on the effects on the environment while the second one concentrates on the intention of the innovator.

There are some other terms that describe innovations whose main purpose is to reduce negative impact on the environment, three of them are most commonly used by researchers: “green”, “environmental” and “sustainable” innovation [6]. While the meaning of “eco”, “green” and "environmental" innovation is very similar, researchers seem to use the term "sustainable" to underline different aspects. According to Brundtland¬ [7], sustainable innovation is defined as "meeting the needs of present without compromising the ability of future generations to meet their own needs" so this term concentrates more on social problems, not only taking into consideration economic and ecological ones [8]. In the last three years, the word "eco-innovation" is the most commonly used in literature and this is the one that will be applied in this work. The field of research of eco-innovations is quite new, articles started to be published in the last decade of the past century, but a boom in publications can be seen since 2009.

Why are eco-innovations being introduced? There are three main levels of eco-innovation drivers: macro, mezzo and micro [6]. In the case of the railway companies the macro level drivers are regulations and technological innovation. This is particularly important in the light of the hypothesis by Porter [9] that environmental regulations stimulate innovations and therefore lead to "win-win" situations where the negative impact on the environment is lessened while the companies' competitiveness grows. This applies well to any transportation industry and fits particularly well with railways due to their general ecological character and competition with highly polluting cars and trucks. Mezzo level drivers are in this case the market trends and the image and reputation of the industry - as mentioned previously the ecological aspect is especially important in the railway context. M,icro level drivers are economical - cost savings achievable by teaching drivers eco-driving techniques have been shown by literature [10; 11] to reach up to 10-20% of total energy costs. These are usually quite significant parts of the budget for railway operators and make eco-innovations of this type a very attractive investment.

Railway timetables are usually designed with a certain time reserve called schedule padding [12]. This serves to limit the negative effects of random delays of single trains on the whole network punctuality. That padding, however, remains unused in normal operation which means that for a given track segment between stations travel times can differ significantly. As Scheepmaker [13] shows, there is an inverse relation between travel time and energy consumption, which means that certain driving techniques lead to energy savings and lower environmental costs. This set of techniques is called eco-driving and is an idea well known and researched both for internal combustion engine (ICE) powered cars and for trucks [14; 15], as well as for electrically or ICE-powered trains [16]. It is important to point out that energy efficiency is only the fourth priority in passenger transport after safety, punctuality and passenger comfort. The problem with train drivers and eco-driving is that in most cases there is no information relayed to the driver about the amount of energy he consumed on a given trip. This makes for a stark contrast to cars and trucks where both the current consumption (in most cases) and the amount of fuel left in the gas tank is well known and visible. There are numerous ideas how to implement eco-driving among train drivers [12] ranging from simple pre-ride instructions on how to travel a given route to full-scope Driver Advisory Systems (DAS) which use complete data about track, semaphores, train etc. to calculate exact driving instruction for the driver and display it on a monitor [17]. Introducing these solutions can, however, be quite costly, time-consuming and meet driver resistance, which actually happened during the TRAINER programme in Europe [18]. Simulators used for driver training are designed with focus on safety and correct behaviour training and do not display eco-driving-related information.

3. VIRTUAL REALITY

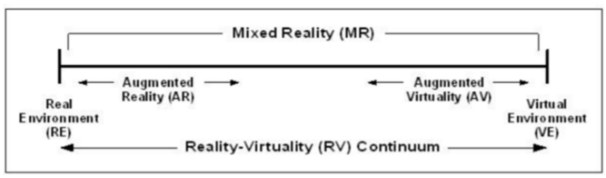

Fig. 1. Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, *77*(12), 1321-1329.

Technological progress in the area of virtual reality has been so swift in the recent years that even the first definitions for the field are beginning to look outdated. The first concepts of virtual reality were created in the 1950s by Morton Heilig [21], who proposed a vision of a simulation so complete and immersive that the user would not be able to differentiate it from reality. He constructed a device, Sensorama, which was the first approximation of what virtual reality could look like. Sensorama was completely mechanical, but the first digital solutions, i.e. by Furness [22] were developed already in the 1960s. It was Furness who designed the first Visually-Coupled Airborne Systems Simulator (VCASS) which would later develop into full-scope aircraft simulators used worldwide for pilot training up to this day.

A modern definition of Virtual Reality has been provided by Milgram and Kishino in 1994 []. According to them a Virtual Reality environment is an environment in which the participant is completely immersed while being able to interact with the artificial world created for the simulation purposes. The world the user is interacting with needs to be completely synthetic and computer-generated- although some physical elements may be added for the sake of increased immersion, as in the case of the device described in this paper. These elements used for steering are also generated in the simulation- their physical counterparts serve to stimulate the sense of touch which remains out of reach for computer-generated graphics.

The lack of computational power and the necessary display systems caused low popularity of virtual reality solutions until the 21st century, when the technological progress made it possible to develop completely new devices. The most popular among them are Oculus Rift acquired and developed by Facebook and Vive created by HTC. These are stand-alone goggles that are intended to be used with a personal computer and usually require a high-quality graphics card. Both solutions also require a tracking camera, although these cameras differ significantly- Rift uses a single sensor named Constellation [Constellation] and places before the user, whereas Vive uses two Lighthouse sensors which enables it to track a larger area [Vive]. Control is achieved by using a special pilot or via a simple x-box gaming pad. Samsung developed Gear goggles for use with its smartphones, which significantly reduces image quality but increases user freedom due to the lack of connecting cables. It is also worth mentioning that Sony created VR goggles for use with its PlayStation gaming console.

Virtual reality has become especially popular in these branches of business where providing training in real conditions is particularly difficult or impossible, like medicine, extra-terrestrial flights and the military [23]. Although railways do not necessarily have the same problem with providing realistic training as these branches, there are certain types of situations which cannot be taught on a real train, i.e. collisions, catastrophes, fires etc.

4. RAILWAY SIMULATORS

Using simulators for training vehicle drivers is very popular among transport operators because it enables the simulation of situations which are very difficult or impossible to recreate on a real vehicle. These are scenarios like accidents, equipment failures, dangerous situations etc. Simulators can also significantly reduce training costs when used in the first part of practical training. It is substantially cheaper to teach drivers the basics of vehicle handling on a simulator than to use real vehicles which have to be taken out of revenue service. Furthermore, some of the most modern solutions enable the training operator to monitor trainee reactions - like reaction time, concentration, stress or fatigue [24]. Observing how the driver behaves in critical situations is very important for the safety of transportation and using this monitoring technique makes it possible for the operator to determine which of the newly trained drivers might not be best suited for the job from the psychological point of view. These devices were not, however, designed with energy efficiency of the driver as their focus which means that although they can be used to train eco-driving skills the information they provide will usually not be helpful in that context.

The railway simulator market is well developed. There are two main producers - the French company CORYS which has already supplied ca. 900 devices [25] and the Spanish company Lander [26]. There are also numerous more local suppliers, including producers from Japan, UK, Australia or US. The simulators offered on the market vary greatly in their size, price and setup, which can range from a simple monitor on a table to a full-scale simulator mounted on a platform with 6 degrees of freedom of movement. This last type of solution is the most realistic one, but also the most expensive and requires extensive space both for the simulator cab as well as for the instructor station and for the computers. QUMAK company from Poland recently presented a more mobile solution based on a truck which could enable the operator to transfer the training station between its dispersed locations instead of bringing drivers over to one training centre [27].

All these solutions are capable of providing a good immersive experience, they are, however, quite costly. They are also usually focused on safety and vehicle handling [28]. The area of energy efficiency has usually not been included in the requirements for such devices and most of them do not display even the most basic information about this subject such as energy consumption or power intake. Their immersion potential is also limited - their construction is usually based on classical displays, often only in front of the driver. Meanwhile research has shown that the key to the realistic feel of the simulation for the trainee is the sideway display [29]. This immersion feeling is easily achievable using virtual reality goggles like Oculus.

It seems therefore that a new device could be designed specifically to help train drivers eco-driving skills by displaying the relevant energy consumption data while using the new VR technologies in order to increase immersion, reduce costs and provide an easily transferable simulator.

5. VIRTUAL REALITY RAILWAY SIMULATOR EXPERIMENT

5.1. DESIGN OF THE VR SIMULATOR

The concept of a virtual reality railway simulator is based on two distinct components: hardware and software. The most important part of the hardware component are the virtual reality goggles. In the demo version described in this paper it was Oculus Rift. The goggles require an additional tracking camera and were also supported by a LeapMotion hands detector in order to make the immersion more powerful - users could see their own hands in the simulation. The second part is the computer - it has to be powerful enough and equipped with a top-quality graphics card due to the computational requirements of simulation calculations. The last part of the hardware component is the driver panel with train controls. These are included in order to make the haptic part of the simulation more realistic. The number of real world train controls is adjustable and depends on the circumstances. Whereas for the demo version only the train controller (to control speed, acceleration and braking) and the dead-man's switch (a device to monitor if the driver is conscious) were included, in professional training devices a full railway driver panel should probably be included.

The software component of the simulator is composed of three distinct parts. The first one is the whole simulation logic and physics. It is responsible for collecting signals from the haptic part of the simulator (i.e. train controller) and user position to calculate the train movement and position as well as managing the conditions of disqualification. In the context of the demo version, the user was disqualified for over speeding, failing to stop at the end station, not pressing the dead-man's switch on time or failing to arrive on time. The second part of the software component is the 3D environment. It needs to be as realistic as possible while still manageable for the computer and the graphics card - otherwise the refresh rate can drop too low which can cause the immersive feeling to be disrupted. In the case of the demo version an artificial, 7-kilometer route has been prepared based on real signals from the Polish railway system. Future implementations of the device will probably need to be based on recreating real world routes in 3D graphics, which can be a costly and time-demanding problem in itself. The last part of the software component is the 3D simulated driver cab. It needs to correspond well with the real driver panel placed in the simulator, and reflect the changes happening during simulation due to user decisions and feedback - otherwise the immersion feeling will be disrupted by the discrepancy between the layout of the panel in VR and the sensory signals provided by the hands of the user. Such a device would be an eco-innovation because it would be new to any railway organisation and through its operation a significant ecological impact can be achieved when used as a part of an eco-driving initiative in the company.

5.2. PARTICIPANTS, RESEARCH METHODS AND TECHNIQUES

The first, demonstrative version of the proposed device was prepared for InnoTrans 2016. InnoTrans is the largest international trade fair [30] for the railway market and takes place in Berlin, Germany biennially. In 2016 there were almost 3000 exhibitors and nearly 150 000 visitors for the fair, which took place between the 20th and 23rd of September. Visitors are almost exclusively people either working in the railway business or railway enthusiasts. This includes CEOs, high government representatives as well as numerous directors, managers, train drivers etc. Two devices were available to the general public at the InnoTrans. The VR simulators were an essential part of the REDS company stand and served to promote eco-driving ideas and techniques. The simulators proved to be very popular and both devices were occupied most of the time for four days of the fair.

Each visit to the stand took about 20 minutes which would begin with an introduction to the simulator and its controls and a short virtual reality instruction. After these preparations, the visitor would travel a 7km segment between two stations in approximately 6 minutes and receive feedback about his performance - whether he or she managed to complete the task successfully and how much energy had been used. The feedback was provided in a slightly gamified form - each guest would be qualified into one of 3 groups of results: economical (under 23.81 kWh), average (between 23.81 kWh and 30.16 kWh) and inefficient (over 30.16 kWh).

Each person taking part in the simulation was asked to fill a survey about their experience and attitude towards virtual reality in the railway context. The questionnaire was a form of direct measurement of attitudes. The survey consisted of 4 closed questions and 1 open. The questionnaire was concise in order to assure the highest possible response rate. Due to time constraints and high volumes of traffic at the stand some guests did not fill the survey, the total amount of stand visitors was higher than the number of questionnaires but despite this the response rate was high and amounted to 85%.

5.3. ATTITUDES AND ACCEPTABILITY – RESEARCH RESULTS

During the four days of the exhibition 144 surveys were filled. Questionnaires were anonymous but information regarding age range and nationality was included for statistical reasons. 32 different countries from 6 different continents were mentioned in the survey with the majority of guests coming from Germany (21% of all respondents) or Poland (14% respectively). This is not surprising due to the fact that REDS is a Polish company and the exhibition took place in Germany. Most respondents belonged to the 30-39 age group.

Table 1. Age distribution of respondents.

Age	N	%	Cumulative %
ND	9	6.3	6.3
<20	6	4.2	10.4
20-29	35	24.3	35.4
30-39	45	31.3	66.7
40-49	31	21.5	88.2
50-59	15	10.4	98.6
60-69	2	1.4	100.0
>70	1	.7	11.1
Total	144	100.0	

The closed part of the questionnaire consisted of the following questions:
Q1: How would you rate your experience on the REDS VR train simulator?
Q2: How would you rate the quality of simulation?
Q3: How similar is this simulation to the real world in your opinion?
Q4: How would you rate the idea to supplement train driver training with VR simulation?

The answers were to be given in a symmetrical five-point Likert scale. Table 2 presents the descriptive statistics for the closed questions from the survey.

Table 2. Descriptive statistics for Q1-Q4.

	N	Min	Max	Mean	SD
Q1	143	2	5	4.59	.573
Q2	143	2	5	4.41	.654
Q3	140	3	5	4.18	.626
Q4	142	3	5	4.73	.493
N	139				

The results were generally positive with particularly high averages for question 1 (M=4.59, SD=0.573) and question 4 (M=4.73, SD=0.493). This means that respondents rated their experience on the simulator very highly and they strongly support the idea to supplement train driver training with VR simulation. It is also worth mentioning that for questions 3 and 4 there were no negative answers (Min=3). Table 3 presents the correlations between the answers given to four closed-ended questions.

Table 2. Spearman's rho correlations for Q1-Q4.

		Q1	Q2	Q3	Q4
Q1	Correlation	1.000	.468**	.404**	.272**
	Sig. (2-tailed)	.	.000	.000	.001
	N	143	143	140	142
Q2	Correlation	.468**	1.000	.528**	.203*
	Sig. (2-tailed)	.000	.	.000	.015
	N	143	143	140	142
Q3	Correlation	.404**	.528**	1.000	.054
	Sig. (2-tailed)	.000	.000	.	.528
	N	140	140	140	139
Q4	Correlation	.272**	.203*	.054	1.000
	Sig. (2-tailed)	.001	.015	.528	.
	N	142	142	139	142

Almost all of the questions in the survey proved to be positively correlated with the single exception of questions 3 and 4. The positive correlations can be interpreted as follows:

Q1 & Q2: the higher people rate the quality of simulation, the better their experience on the simulator is
Q1 & Q3: the more similar the simulation is to the real world, the higher people rate their experience on the simulator
Q1 & Q4: the higher people rate their experience on the simulator, the more likely they are to support the idea to supplement train driver training with VR simulation
Q2 & Q3: the more similar the simulation is to the real world, the higher people rate the quality of simulation
Q2 & Q4: the higher people rate the quality of simulation, the more likely they are to support the idea to supplement train driver training with VR simulation.

The only exception of no correlation between answers to questions 3 and 4 means that while the virtual reality simulation may still not be close enough to the real world, most survey participants still find that it can supplement train driver training in a meaningful way. The strongest correlation is between questions 2 and 3 which stems from the fact that the quality of simulation is usually rated by people in comparison with the real world.

What can also be interesting, is the fact that there is no statistically significant correlation between age and answers given to any of all four closed-ended questions (table 4). This means that regardless of age, the attitudes towards the simulator are similar.

Table 4. Spearman's rho correlations for age groups and Q1-Q4.

		Q1	Q2	Q3	Q4
Age_ groups	Correlation	0.009	0.152	0.046	0.038
	Sig. (2-tailed)	0.920	0.079	0.606	0.666
	N	134	134	131	133

The open-ended question was designed to provide additional more qualitative feedback on the proposed solution. 32 people out of 144 decided to leave supplementary comments. The negative feedback concerned mainly the resolution of the Oculus goggles used in the simulator. The current Oculus resolution, 2160x1200 pixels can be problematic when displaying semaphores in the distance, especially at night, when in the real world their aspect can be seen from as far as 2 kilometres. Most train drivers complained about the missing real world controls - the horn signal and pneumatic brake in particular. Including them would probably make the disqualification rate much higher and their omission was a conscious decision by REDS company, which took into account the fact that most InnoTrans guests are not professional train drivers. Positive feedback was usually a way of expressing enthusiasm for the device which could not be expressed using the closed part of the questionnaire. Among the answers given there were a few like:

"Unlimited applications for VR technology - very exciting!"
"Good and very cool! Nice job. Nice idea."
"Amazing experience!"
"That was a lot of fun!!!"

Generally, the proposed VR-based simulator solution was very well received. Most visitors accepted it and even those who pointed out certain limitations to its current design and technology usually supported the idea of using it as a training tool for train drivers.

6. CONCLUSIONS

The general attitude towards the proposed, demonstrative version of the Virtual Reality railway simulator was very positive. Although some responders have pointed out the limitations of the current version stemming from low goggle resolution most surveyed visitors saw a large potential for this type of device in professional train driver training. Some guests also suggested extending this type of simulator to encompass other types of rail vehicles than mainline rail, explicitly naming trams and subways as transportation means that could also benefit from such a learning, 3D environment. No difference in attitude towards the virtual reality was observed with regards to the age of responders. This type of research could be repeated among the train driver group only in order to determine whether the proposed solution is received as well among them.

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