APPENDICES

GRADUATION PROJECT IPD

IMMERSIVE SAFETY & SECURITY TRAINING

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MASTER THESIS APPENDICES

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A. Interview notes trainers

4 CSST TRAINERS WERE INTERVIEWED ABOUT THEIR TEACHING METHODS, VIEWS ON THE PROGRAMME AND THEIR MOST RELEVANT LEARNING GOALS. FOR THE SAKE OF PRIVACY, THEIR NAMES HAVE BEEN REMOVED FROM THESE INTERVIEW NOTES.

Trainer A

Learning goals

- **What do you hope by the end of a training day has changed or improved among the participants?**
  - Knowledge of model / procedures (me / KLM / you)
- **What teaching goals do you have, which are in currently hard or impossible to achieve?**
  - Some colleagues potentially lack background knowledge
- **What learning goals do you think could be served with the possibilities of virtual simulation (VR / MR)?**
  - Is excited about it and open to these developments
  - Does not have a clear view of how it would be implemented
  - KLM is typically slow in adopting new computer technologies and systems

Teaching style

- **How would you describe your teaching strategy?**
  - Calm and stress free
  - Open to questions
  - Experienced
  - Humorous
  - Interactive
- **What is the goal behind all the gamification?**
  - Isn't a fan of it, thinks it often distracts from the content of the programme.
  - Take own approach, depending on what is most useful and efficient
  - Examination is primary source of stress for participants
- **The day is quite social and co-operative. Is this intentional and what purpose does this serve?**
  - Thinks that participants should be allowed some space to learn with low pressure

Evaluation

- **At what point would people fail these tests, or would the teacher intervene?**
  - In the recurrent, people are never given a failing evaluation
  - Examination is more frequent in the initial training, and more critical
  - Negative feedback is mostly avoided within KLM.
- **How do you reflect upon the results (with or without participants)?**
  - What went well (KLM focuses mostly on positive feedback, small mistakes are easily forgiven)
  - Often participants refrain from doing certain steps because it is a simulation.
- **In what areas do participants typically need most improvement?**
  - FSSM (many only do the question, don't really read)
  - Logical thinking, which is missing in the training programme for the most part.
  - There is some conflict between regulation (FSSM) and logical thinking (professional judgment)

Trainer B

Learning goals

- **What do you hope by the end of a training day has changed or improved among the participants?**
  - Increase understanding, regarding background info and reasoning
  - Have fun and gain a positive attitude towards safety
- **What teaching goals do you have, which are in currently hard or impossible to achieve?**
  - Videos >awareness, motivation
- **What learning goals do you think could be served with the possibilities of virtual simulation (VR / MR)?**
  - Context and surroundings (realistic background and presence)
  - Being able to imagine and communicate what a scenario would be like.

Teaching style

- **How would you describe your teaching strategy?**
  - Relaxed
  - Humorous >this lowers the threshold for interaction. Happy people learn more easily
  - Empathetic
- **What is the goal behind all the gamification?**
  - Lowering threshold and being active
  - Surprise effect
  - Trainer is generally positive towards this
- **The day is quite social and co-operative. Is this intentional and what purpose does this serve?**
  - This is simply how KLM is in practice, also on planes.

Evaluation

- **At what point would people fail these tests, or would the teacher intervene?**
  - Sometimes people are to absorbed in their own experiences, views and stories.
  - People focus on what is wrong or not allowed to do, rather than what is best in that moment. Trainer would ask why they think that.
- **How do you reflect upon the results (with or without participants)?**
  - Debriefing in the classroom afterwards.
  - Point out and discuss points of improvement (e.g. to take into account how passengers would behave)

Trainer C

Learning goals

- **What do you hope by the end of a training day has changed or improved among the participants?**
  - Awareness
  - The 'why'
  - Mostly improved theory knowledge
- **What teaching goals do you have, which are in currently hard or impossible to achieve?**
  - Not yet
- **What learning goals do you think could be served with the possibilities of virtual simulation (VR / MR)?**
  - Lots of future potential
  - Better, more tactile replication of scenarios
  - Improved understanding

Teaching style

- **How would you describe your teaching strategy?**
  - Having a nice, open atmosphere
  - Being serious whenever necessary
- **What is the goal behind all the gamification?**
  - Is positive about this
  - Works better than traditional lecturing
  - Target group is very practically oriented
- **The day is quite social and co-operative. Is this intentional and what purpose does this serve?**
  - It is important that everybody gets some attention.

Evaluation

- **How do you reflect upon the results (with or without participants)?**
  - Asking open questions
  - Question responses of participants on their iPad are not registered
  - Not necessary to inspect students very closely
  - Listen to participants
- **In what areas do participants typically need most improvement?**
  - Awareness can improve by increasing the number of simulator scenarios

Trainer D

Learning goals

- **What do you hope by the end of a training day has changed or improved among the participants?**
  - Prevent that people forget things
  - Theory knowledge should be acquired at home, practice at CSST.
  - Hopes for changes in attitude and behaviour, but thinks this is very challenging to achieve.
- **What teaching goals do you have, which are in currently hard or impossible to achieve?**
  - Change of behaviour
  - More realism with a more challenging training
  - The 'openness' and 'honesty' are not always real
  - Participants are very well behaved, but almost artificial
- **What learning goals do you think could be served with the possibilities of virtual simulation (VR / MR)?**
  - Allowing for scenarios to go completely wrong (based

on actions).

Teaching style

- **How would you describe your teaching strategy?**
  - Keeps at the same level as group
  - Very direct, sometimes to a fault
  - No nonsense
  - Positive attitude, but honest about what can go wrong

- **What is the goal behind all the gamification?**
  - Is positive about it
  - Works well to activate people

- **The day is quite social and co-operative. Is this intentional and what purpose does this serve?**
  - Current recurrent training is overly specified: participants must at certain moments give each other feedback, but this is hard to keep an eye on and most don't dare to express themselves critically. Often the exercises are too easy, so there is nothing to say.

Evaluation

- **At what point would people fail these tests, or would the teacher intervene?**
  - Would immediately intervene when observing something goes wrong, and give a good example.

- **How do you reflect upon the results (with or without participants)?**
  - Doesn't feel positive about current feedback systems: People don't gain much from it, in its current form. Also participants are too impatient to take time to reflect afterwards. Reflection needs to be generalized to entire group, otherwise there is no time.

- **In what areas do participants typically need most improvement?**
  - Dealing with hand luggage and the conflict between regulation and service.

B. Interview notes experts

SEVERAL PEOPLE WITH SPECIALIZED KNOWLEDGE WERE INTERVIEWED.

Interview Henny van Kessel

Education Consultant at KLM

Date: 8 March 2017

General

- What is your role at KLM? What kind of projects are you involved with?
  - Learning consultant at Engineering & Maintenance
  - Works on hololens application for teaching theoretical functioning of AC system, which is not normally visible.
  - Shorten lesson time
  - Increase learning and understanding
  - Social and cooperative exercises, integrated in new lesson plan

AR / MR / VR

AR has the potential to improve memory, task performance, enjoyment and learning. A couple of discussion points:

- Learning curve (new tech, new interactions)
  - Introduction technology
  - Orientation game
  - Users should use the AR headset for 10 minutes at the time at most.
- Heavy on head
- AR is nicer than VR, more social

Measurements during research:

- Two groups of three teams, one with traditional lessons, one group with hololens lesson plan
- Measurements
  - Preliminary questionnaire
  - Eye tracker
  - Evaluation after experiment, through test and questionnaire
  - Examination
  - Human factors
  - Experience and interaction
  - Ergonomics
  - System logics (air conditioning)
- Interface design for learning (3D artifacts, 3D positioned content, 2D overlays)
- Interactions for learning (cognitive, mimic interaction, physical interaction)

My Research

- Is there data on the roles stress and anxiety play on performance in practice?
  - Time pressure influences decision making, missing in current training at EM.
  - Ground stewardesses (sold to ROC), incorporates stress and handling passengers. App was developed for behavioural training around aggression
  - Role play on computer at L&D (Learning & Development) for sales (traintool, moovs, Edwin Bleumink)

General Notes

- Topics to look into:
  - Stichting Valk, regarding fear of flying
  - Remote troubleshooting project: MCC and line maintenance for remote troubleshooting

Interview Guido Helmerhorst

14 March 2017

Interview with Guido Helmerhorst, Social, Business & Technology Architect + Innovation Manager at corporate innovation at KLM

Regarding: Technological Innovation Goals at KLM, specifically VR / AR / MR

General

What is your role at KLM? What are you currently working on?

- Gamification / serious games in KLM
  - Betrokken EM Hangar VR evacuation Pilot
  - Triggers throughout organization (SST, ground services)
- Meaningful experiences, VR, experiments
- Planning implementations (agile / lean / startup style)
- Business Cases van innovatie (strategy + financials)
- Packages projects for management (ideally would not need this role)

Innovation goals

What are the main drivers of technological innovation within KLM?

- Suppliers
- Academia
- Startups (rol innovation department)
- Competitors
- Not top-down: first experiment >pitch to management, which is the problematic part:
  - Disruption aversion (stability preferred, avoid mistakes)
  - Ease of implementation
  - Good business case (Mostly financials)
  - Resistance from other parties (e.g. trainers with fear of being replaced)

Where does KLM see value for VR most strongly?

- Shift planning to coordination
  - From planning of resources (logistics, trainers, facilities)
  - To coordination (responsibility for trainee)
  - Portability / scalability (implement directly at airports)

Where does KLM see value for AR / MR most strongly?

- Again, planning and coordination

On what timeline and scale will these technologies be implemented throughout KLM?

- Within 5 years there should be successful completed experiments within most of KLMs departments
- Fundamental change will probably be only realised within 10 years.
- AR / MR takes longer, because it requires stronger integration (VR is more isolated)
  - Required developers, but mostly translation of existing programmes and knowledge.

What does KLM want to communicate to the outside world? Other airlines / competition, Customers / passengers, Regulators

- Be perceived as the most innovative airline of Europe / pioneering
- Externe branding van interne innovatie gebeurd niet goed

Approach

What are the main challenges and pitfalls for successfully developing new products / solutions within KLM and the aviation industry? Any specific to VR / MR?

- Multiple levels
  - Organized by division >innovation doesn't travel well
  - Management >does it fit strategical goals and choices
  - Dealing with employees and integration

General Notes

Topics to look into:

- What is the learning philosophy?
- What is the vision of Flight Operations (OGSM)?
- Innovation CSST can also damage safety brand
- Ad van Haren (innovation re: safety)

Interview Ard Rombout

Manager CSST (Expertise regulation compliance)

What is your role within the safety / security training department?

- Responsible for part-time trainers / part-time flight / cabin crew.
- Compliance to law, regulation and procedure of training

Where are regulation and requirements of CSST documented?

- OM Trainings Operations Manual, combining:
  - EASA (IATA + European additions and refinements)
  - IOSA (Agreement airlines on safety standard)
  - KLM Standard (Additions to EASA + IOSA)
- All parties have their own safety auditors and inspectors
- The are no regulations on how training participants are evaluated, only the requirement for an evaluation system to exist.
  - Airline is responsible for their safety standards.

How do you approach the implementation of the regulations?

- Since 3 years that Ard works there: CSST knows what is most important to incorporate in the training (focus points and teaching style), rather than solely following what regulation prescribes.
- Safety / service balance, safest course of action / improvisation in training from KLM trainers organization.

Which parts of the training programmes are fully mandatory, which aren't (and which partly?)

- 90% are mandatory topics, but (with the exception of the door trainer) the training is not specified in the legislation in a lot of detail.

What is the general process of proposing an exception or change of regulation (e.g. when implementing virtual replacements of training procedures)?

- If it works well, and it simulation the experience well, it may be approved by the inspectors. Basically, it is their professional judgment.

What are the main challenges in making a regulation compliant training programme?

- Alternative means of compliance (ILT)

Interview Chris Koomen

Non-structured interview / meeting with Chris Koomen, E&M Aircraft Mechanic involved with VR emergency evacuation training at Hangar 14.

9 March 2017

Experiencing VR Evacuation

- 360 video's with gaze based interaction choices
- You can do things wrong and experience the consequences
  - If you take the lift you end up trapped in the elevator filling with smoke
  - If you go the wrong way when outside you are in the way of fire trucks.
- Rating on your overall performance
- Alarm sounds (and to some extent the smoke effects) induce a lot of stress and urgency
- Simple interactions and no actual movement, but still feels more real and urgent than conventional fire drills.
- Social aspect is missing, no collaboration or reliance on others
- Personal feedback, but no public evaluation or recording of results

Notes from conversation

- Research on difference doing evac training in VR and doing it on a notebook
- Next: VR training for maintenance
  - Very portable (offline, smartphone based)
  - Allow people to make mistakes
- If the simulations show that some people have a bad stress response, or make fatal mistakes, how do you deal with this?
  - Mistakes / evaluation policy
  - How far do you go in inducing stress
  - VR Evacuation caused some stress reactions in testing
  - Other VR experiments caused people to freeze up completely

Interview Re-Lion

Interviewee: Christian Haarmeijer (Marketing & Sales @ Re-Lion)

Date: 25 April

Prepared Questions

How do you go about communication and collaboration during simulations?

- Physical contact / presence in space
- Radio contact within team and with instructor
- Virtually visible presence (+ full body tracking)

How can a simulation be observed and evaluated?

- There is a spectator station, where all recorded data from the simulation can be replayed in the original virtual 3D space.
- No automated analysis of performance, that remains job of instructor

What kind of data is registered?

- Full body tracking (position + joints)
- Speech + audio
- Events (e.g. use of ammunition, explosions, etc.)
- Physiology is topic of interest, but not currently implemented. Stress research is ongoing (using heart rate monitoring) at TNO.

What is observed in terms of stress response? To what extend does the training prepare for the pressures of real life scenarios?

- They are doing research in collaboration with TNO regarding stress (Claudi Koerhuis & Olaf Binsch).
- The VR training prepares soldiers better for a diverse set of stressful scenarios than live training because of increased flexibility and diversity of the training. It performs better at tactical and mental training, but slightly worse at training technique and physique.

What interactions are enabled in the simulations?

- High level of detail depending on the simulated context
- Physical props (weapons or firefighting tools) are accurately physically and digitally replicated.
- Other props (e.g. grenades and dynamic parts of the environment) are purely virtual, but interactions are enabled by bodily motion and buttons on the suit.
- Social interactions are enabled by radio / microphone communication. In case virtual humanoids need to have complex interactions with the training participants, the instructor can 'take over their body' using the Black suit (Basically role play by proxy).

What are currently the biggest limitations?

- Space is often limiting. For that reason training outside is explored. The radio system for data transmission is technically very easily scaled up.

What is currently the biggest difference with reality?

- You don't feel the purely virtual artifacts. There are some ongoing experiments with haptics (vibration based), but fully haptic (including motion restriction) exoskeletons would be too limiting in free movement with current technologies.

What kind of system is used to enable VR with so much freedom of movement?

- Radio system in Exercise Control (Excon) box, transmitting position data and data from sensor fusion system
- VR Backpack per participant, each rendering the virtual space and processing data. However, the Excon is the main instance where the core of the data processing happens and the simulation is run from

How can instructors control what happens in the simulation?

- Terrain builder tool: reasonably user friendly tool that allows turning diverse sources of data into custom maps for the simulation
- Excon system allows some adjustments, but most events are pre-programmed (limited change during simulation).

- Trainers can take over virtual humanoids using the body suit
- Trainers can become visible / invisible and intervene in simulation

How is the presence users experience when using the black-suit or red-suit?

- You can observe very natural responses in them (e.g. loss of balance and disorientation in response to flash grenade)

Who are your customers?

- Dutch Ministry of Defense / Army (Involved from early on)
- International Ministries of Defense (Slightly customized implementations, ongoing)
- Dutch Firefighters (Still mostly a prototype, red-suit is somewhat on the backburner)

What is your business model?

- 5 year contract with Defense, performance based model
- Defense is owner of hardware and software, because rent model doesn't work with such a niche market. However, Re-Lion is responsible for keeping it running

How do fixed costs compare to variable costs with your systems?

- A lot is replicable between clients. Initial investments were high (some subsidies, mostly self-financed), and as such having a single client isn't viable.
- Both software and hardware are custom developed internally (industrial design, PCB design, render engine, etc.) to be able to control everything and guarantee a working solution to clients.

General Notes

- Company started 18 years ago, originating from Twente University of Technology. Started of with a focus on 3D software projects, but not as specific as now.
- Currently the company has 25 employees, including software engineers, electrical engineers, industrial designers, etc.
- First demonstrator black suit was delivered to Ministry of Defense in 2010, and has seen several updated versions since. It took 12 years to build and was largely subsidized through previous projects.
- Instructors and technicians of the system get training courses to use the system. Soldiers who train with the system are instructed through a physical card based system.
- Large value of system is that it saves a lot of time and resources versus live training.

Components of the system:

- Body suits (black-suit and red-suit)
- Exercise control (excon), including radio transmitters
- Spectator station
- Scenario development station
- Battery management station

Sounds in simulation:

- Contextual audio
- Speech / radio
- Sound effects
- Roleplay / virtual characters respond to the sounds you make

Interview Ol af Binsch (TNO)

Date: 6 June 2017

Interviewee: Olaf Binsch (Psychologist Mental Performance, Resilience, VR training)

What was the topic of your research for the VR training of infantry?

- Training of surveillance procedures
  - Participant in stationary position of gunner in truck, driving through landscape and villages
- Stress and workload were measured and classified in profiles according to Blascovich's model of Arousal Regulation.
- Improving training for stressful situations
- Stimuli / tasks during research
  - Electric shocks
  - Multiple choice / math questions
  - Pre-programmed scenarios during surveillance
  - Observation tasks

What were the findings? What physiological measures were taken?

- Blascovich biopsychosocial model of Arousal Regulation > stress profiles
- Skin conductivity, heart rate and blood pressure, which together give a good reading of experience stress.
  - Measures were taken whilst seated
  - The baseline measure (e.g. of heart rate) were taken in separate moments from the test.
- Performance scores based on task completion, error rates, and completion rate.

Which physiological measures are the most indicative of stress, physical effort and workload? How can you distinguish?

- Stress is not the equal to workload. Besides yerkes-dodson law, the social psychological model of Blascovich is relevant here: Stress is indicated by a relation between blood pressure and heart rate.
- Appraisal of stimuli
  - People with poor stress response: more training or alternative individual training
  - Everyone should be trained personally, based on the trainer's judgement, for an optimal stress response.

How can you say something about the causality of stress or task load without isolating each factor?

- You can't, you have to research per factor.
- TNO has developed standardized appraisal questionnaires regarding stress and task load factors internally.

What can you generally say about the roles of stress and the uncertainty of a critical situation on performance and behaviour?

- In the research diverse things could happen during surveillance
- Procedures and simple actions can be reliably taught using drill training, and then be executed on 'automatic pilot'
- Dealing with stress and pressure is important because you can't train complex scenarios with drill based training. Real life scenarios are almost always more complicated than just the procedure.

How reliable are these drill-based trainings in stressful situations? Are blackouts or alternate executions common? (In relation to personal research findings)

- Is not familiar without the blackout behaviour, but this could very well be due to the use of VR itself.
- According to the Blascovich model everyone should get tailored training to optimally deal with stress, which is something VR is very useful for.

When you distinguish between following procedures and professional judgement in critical situations, is there a difference in how people behave?

- As mentioned, drill-based training is effective for procedures because people can execute them on automatic pilot (such as shooting a gun). These actions should be done reliably, as there is no margin for error. It is however not effective for ambiguous or more complex scenarios.

C. Research Paper

THE FOLLOWING IS A DRAFT VERSION OF THE PAPER SUBMITTED TO IEEE VR. IN ADDITION, THIS INCLUDES DOCUMENTATION OF THE RESEARCH PILOT

Virtual Reality as a means for Cabin Crew Safety and Security Training in the Aviation Industry

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***Abstract*—Simulation training of airline cabin personnel is an effective, low-risk way of preparing for emergencies. As these simulations are abstractions of real-life emergencies, they typically lack certain stimuli (sounds, passengers, turbulence, aircraft interior, etc.) and context. However, little research has been done into how this abstraction affects the decision making, mindset and behaviour of the personnel being trained. Stress, in particular, has been shown to alter how one observes, processes and behaves in a critical situation. In this study, virtual reality (VR) is assessed as a means of creating training exercises for the Crew Safety and Security department of KLM, where a more close approximation of the contextual stimuli of a cabin emergency is simulated. In a repeated-measures crossover study, participants are subjected to two in-cabin fire fighting exercises, one in a traditional fire fighting simulator (a fire proof mockup of part of an aircraft), one in a VR cabin environment. For both exercises, task load, heart rate, performance and presence are measured and compared. The study shows that the VR exercise has a higher task load and results in slightly worse performance. The data suggests an increase in stress and arousal in VR relative to traditional training, although not conclusively due to the limited sample size. No significant differences in presence could be found, although the exercises differ in how presence is achieved. Some smaller patterns are found in the data, most notably the perceived realism of the VR environment being higher while participants claim their actions in the traditional exercise are more representative.**

***Index Terms*—Virtual Reality, Immersion, Presence, Stress, Simulation, Training, Aviation, Safety, Security, Fire fighting**

I. Introduction

Simulation based personnel training is used for tasks where practice is essential but real-world exercise opportunities are not feasible due to limited resources or constraints such as safety. It has proven to be an effective didactical tool in various industries [1, 2, 3], by displaying a clear link between cause and effect and enabling repeated practice. Freeman et al. [2] found that in training for medical aid in disaster response case simulation training can be used to improve cognitive skills by depicting the succession of physiological changes occurring in the patient as a result of the natural course of the trauma, optimal and suboptimal interventions chosen, and the passage of time.

A potential issue with the simulation training for critical situations and emergencies is the uncertainty in how the simulations level of abstraction influences its users performance. Such abstraction can include, for instance, the absence of human actors (e.g. a CPR dummy) or the absence of the actual threat (e.g. in case of a fire drill). While simulations do not necessitate a high fidelity in order to effectively convey knowledge, skill and behaviour [4], it remains necessary to evaluate which aspects of a critical situation need to be incorporated in the simulation to retain what makes such a situation challenging to deal with. Exclusion of an aspect risks that a trainee will not be adequately equipped to deal with that aspect in real life.

Among these aspects are those that have the potential to induce acute stress, as stress response is of influence on task execution and performance. The Yerkes-Dodson Law [5] shows an empirically established relation between arousal (result of stress) and task performance, for which there is an optimum. As such, too little or too much stress in a person is detrimental for performance. Furthermore, stress may alter the decision making process through causing tunneling, an effect where one stops evaluating multiple courses of action and starts disregarding environmental cues in favour of a single focus [6]. Stress has been linked to a reduced ability to process information and follow procedures among medical residents [7], may change style of communication to be less explicit [8]. Lastly, repeated exposure to stressful situations normalizes the effect it has [9]. While it is not certain exactly when and how stress reduces performance, it clearly affects how one observes, makes decisions and behaves.

Relatively little research has been done on how the fidelity and level of abstraction of a simulation training affects presence, stress-response and performance (and their interrelation) of a trainee. Research on the fidelity-presence relation often finds that inclusion of an aspect in the simulation (e.g. body-presence or spatial audio) contributes to presence [10], but that the fidelity of that aspect makes no discernable difference [11, 12]. However, it seems likely that in general a simulation, by approximating its real-world equivalent through the inclusion of its aspects, reduces the chance of a disconnect between training and reality.

Virtual Reality (VR) makes this feasible, as it can be used to give users a sense of presence in a wide variety of virtually simulated contexts and situations [13, 14], with little infrastructural investments and limited resources. When used as a training tool for critical situations, this makes it possible to simulate aspects such as a larger context (surroundings, sounds, crowds) and the consequences the simulated emergency has on that context (e.g. changing circumstances, environmental damage, panic). In military training, VR is the topic of ongoing research and increasingly applied in practice. In a literature study Pallavicini et al. [15] found that VR is effective for military stress management training, identifying adverse effects of stress on performance and increasing individual stress resilience. Furthermore, VR simulation has been used successfully in exposure therapy for phobic anxiety disorders [16], PTSD treatment [17], and the induction of social anxiety and engagement [18, 19] Much of the research focuses on the effectiveness of VR as a training / treatment tool for stressful and critical situations, but fails to compare it to traditional means of training and simulation (or sees it solely as an addition to traditional means). While what traditional means are is contextually dependent, the lack a comparison makes it difficult to judge the validity of VR as a training tool.

This case study concerns the viability and value of virtual reality as a training tool for critical situations in the public aviation industry, where airlines are required to employ simulation exercises in the safety and security training of cabin and flight crew (CSST). The CSST department of the Royal Dutch Airlines (KLM) facilitates simulations in range of scales and abstraction levels, including role-play with unruly passengers, in-cabin fire fighting, CPR training and cabin emergency evacuation training.

To evaluate the value and viability of VR simulation at this department, this research intends to answer the following question: How do VR simulation training and traditional simulation training for critical situations compare, in terms of the presence, performance and stress-response of their users? With a VR simulation designed with the intent of recreating the stressful context of an aircraft cabin during an emergency, the study serves as an exploration of what behaviour such a simulation can evoke that is not present in traditional simulation, and what this says about real-world performance. The scope of the study is limited to the training of in cabin fire fighting, although the validity of the findings for other types of training is discussed.

II. Case Study

The participants of this cross-over study are subjected to two simulation exercises on in-cabin firefighting, one reminiscent of current training practices and one employing virtual reality as its primary means, developed for this study. Fig. 1 presents the relations that are of interest to this study.

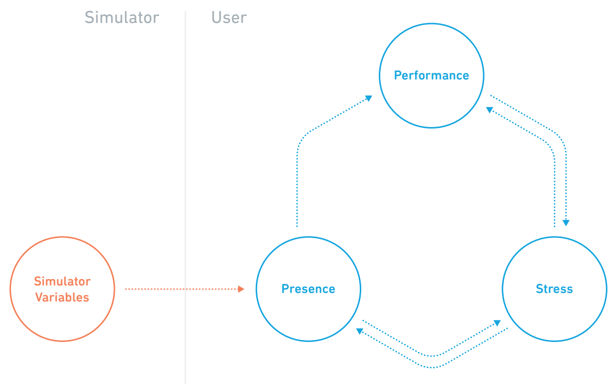

Fig. 1. Relations of interest in this study.

A. Stimuli

The participants are exposed to two in cabin firefighting simulation exercises, presented in Fig. 2, in an alternating order: the traditional training exercise using physical props and real, controlled fire in a fireproofed cabin model and a room-scale (positional tracking of headset and controllers) VR firefighting exercise set in a virtual cabin. The VR exercise is designed to incorporate similar possible courses of action as the traditional training (e.g. notifying the flight crew, grabbing a fire extinguisher), but also introduces some changes to conform to aspects of a real-life cabin fire scenario. For instance, it introduces alternative courses of action (the ability to extinguish using beverage containers and a cooling bath), environmental changes (obscuring smoke) and contextual audio (cockpit announcements, engine noise, panicked passengers, fire alarms).

While the simulation exercises are intentionally designed differently to optimally use their respective means of simulation, the comparison does serve the intent of doing a qualitative assessment of both simulation styles as a whole.

In both exercises, the scenario is one where different types of fires occur at semi-randomized places within the simulated part of the cabin, at randomized times. The subject is given a number of ways to act on the situation in real time. The consequences of her / his actions are influenced by time and execution. The participant is continuously able to act upon the newly developing circumstances.

B. Measurements

Throughout the simulation, the level of acute stress is estimated by making a continuous physiological measurement of the participants heart rate using the Mio Link, a Bluetooth heart rate monitor wristband, as an indicator for arousal. While blood pressure is a better indicator of stress [20] (heightened arousal can be caused by other factors), this can only be measured whilst seated, as it changes based on posture [21]. The heart rate is recorded at a 1 second interval.

During the simulation, the participants performance is recorded through video and, in the case of the VR scenario, screen capturing the virtual point of view of the participant (in the addition to the simulations audio). During analysis, task

Fig. 2. Screen capture of VR simulation with overlaid footage of participant, during start of emergency scenario.

Fig. 3. Screen capture of VR simulation with overlaid footage of participant, during start of emergency scenario.

performance is assessed by CSST training professionals based on a number of subjective criteria (see appendix C). These criteria have been formulated to offer a balanced assessment of the diverse exercises on relevant topics (communication, decision making, following procedures, etc.), as the differences between the simulations and the diverse ways to act responsibly make an objective score metric impractical. After the simulation, a questionnaire (see appendix B) is administered, incorporating the following metrics on 7-point Likert scales:

- NASA Task Load Index: The TLX [22] is a common way of measuring task load in terms of perceived performance, frustration / stress and how challenging the task was.
- ARI questionnaire [23]: This proposed questionnaire is on immersion in Augmented Reality (AR). However, the used selection of questions specifically concern presence and are more broadly applicable.
- Learning objectives: The results in achieving selected learning goals in the interest of the CSST department are represented in two final questions

Additionally the questionnaire includes general questions about the participant (age, experience in aviation, prior experience with fire fighting) and open questions concerning their experiences during the test (general feedback and what factors played a role in creating or breaking immersion).

C. *Procedure*

The research uses a counterbalanced repeated measures design: Each participant is exposed to the two simulation exercises, half of whom start with the VR exercise, while the other half starts with the traditional exercise. This is done to compensate for learning effects in the dataset as a whole. Prior to the simulations, each participant is instructed on the research. For both simulations, each participant is given 90 seconds to acclimatize in the simulated context, to normalize heart rate and familiarize with the environment. After every simulation exercise each participant fills in the questionnaire for that simulation. Finally, any relevant comments and discussions are recorded. The procedure is visualized in fig. 4.

The traditional exercise is facilitated by a fire fighting trainer of the CSST department. The trainer is instructed to do a training as he / she normally would, with the exception of focusing it towards the single concurrent participant. This is done in an effort to closely resemble the regular simulation training procedures. Depending on their teaching style, instructors may interrupt these simulations when a participant is making a mistake, or discuss the expected behaviour on beforehand, making it somewhat reminiscent of a tutorial.

In the VR exercise, the acclimatization period is used to get acquainted with the virtual environment and try out the interactions without the occurrence of an emergency situation.

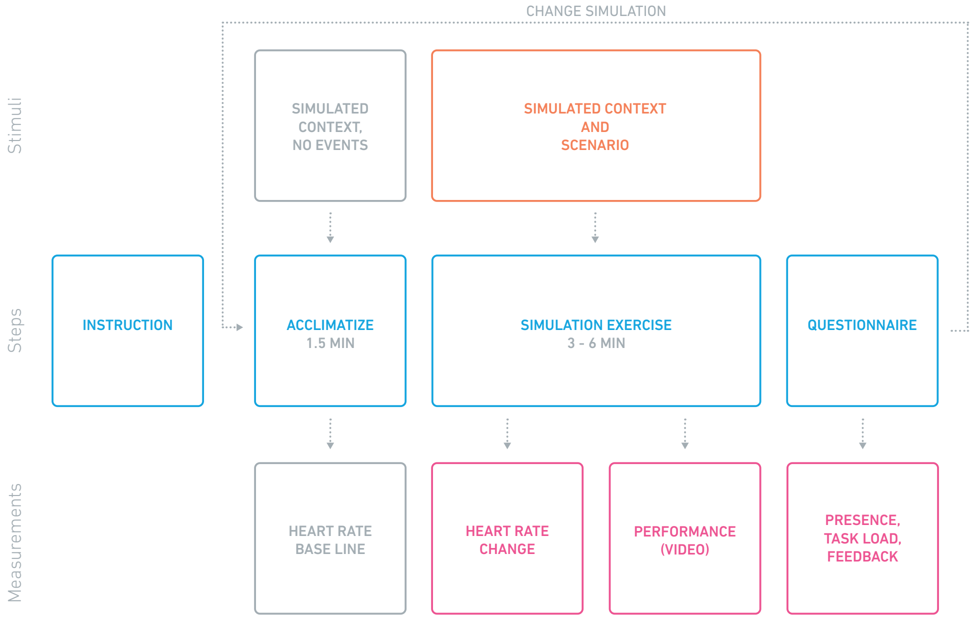

Fig. 4. Research steps per subject.

D. Participants

The study has seven cabin attendants (CAs) as its participants, of whom two were in the process of transferring from a different airline (6 and 13 years experience respectively) and four had no prior experience in the position. One participant has real-life experience with cabin fire, while others have only experienced training.

E. Analysis

Averages and extremes of each subjects heart rates are calculated (normalized relative to the heart rate during acclimatization). Variability of the heart rate is calculated by averaging the relative absolute change in heart rate per second over the duration of the exercise:

$$\overline{H_{variability}} = \frac{\sum_{t=1}^{n} \left| \frac{H(t)-H(t-1)}{H(t)} \right|}{n-1}$$

While actual heart rate variability is measured by interval differences between subsequent beats, this measurement is not performed by the used monitor. A such, the calculated variability is only to be used for comparison between the exercises. The changes of heart rate throughout the exercise are analysed in parallel to recordings of the subjects performance, to identify potential connections, and averaged to observe general progressions.

Performance is assessed with the perceived performance by the participants (part of the questionnaire) and with a 7-point performance rating based on the criteria listed in Appendix C, as judged by a fire fighting trainer of the CSST department.

Using a one-way repeated measures ANOVA, the influence of the simulation type on presence is calculated. The same is done for the performance and stress measurements. Subsequently the average heart rates, TLX scores, subject performance ratings and presence scores are correlated.

III. Results

A. Task load

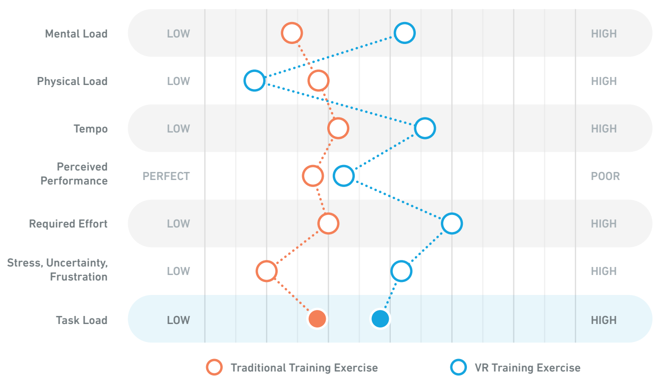

Fig. 5. Average task load ratings per simulation type (n=7).

The task load was on average significantly higher for the VR exercise (3.86, SD=0.67) than for the traditional exercise (2.69, SD=0.55) [Wilks Lambda=0.15, F(1, 5)=28.423, p=.003]. Fig. 5 displays the average rating per question part of the task

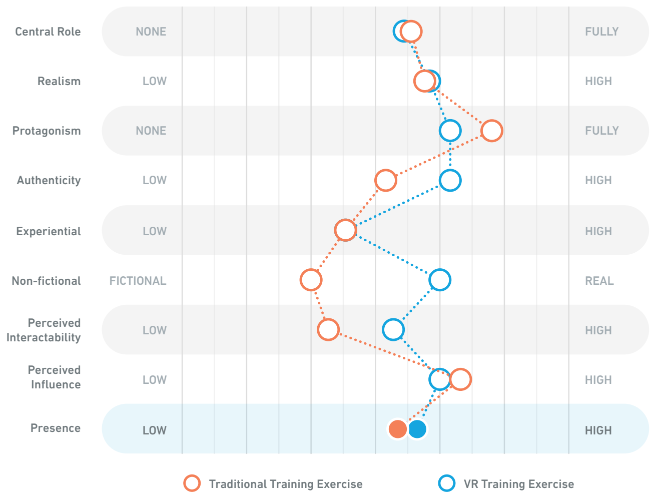

Fig. 6. Average presence ratings per simulation type (n=7).

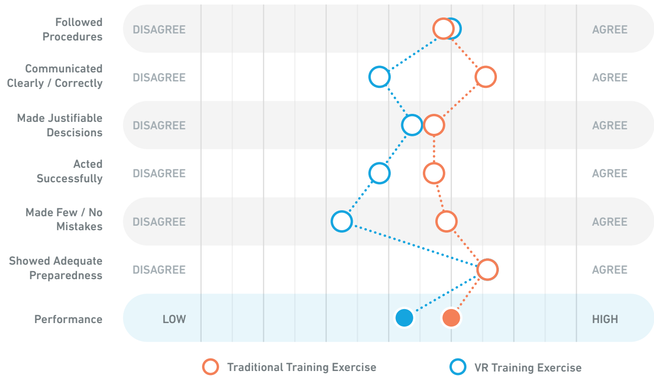

Fig. 7. Average performance rating on Likert scale by instructor per simulation type (n=7).

load metric. Despite the higher perceived tempo in VR and same amount of fires to resolve, participants took much longer to complete the VR exercise (500 s, SD=119) than for the traditional exercise (246 s, SD=26). While this is in part due to the pacing of the simulation (fixed timers and delays), the large variance in VR task completion rate reveals a difference in performance between participants.

B. Presence

Overall average presence scores of the VR exercise (4.68, SD=1.06) and traditional exercise (4.32, SD=1.34) show no significant difference [Wilks Lambda=0.972, F(1, 5)=.146, p=0.718]. However, some difference can be observed in the factors that make up this score (see fig. 6). The VR exercise was perceived as more non-fictional (5.00, SD=1.53) and authentic (5.14, SD=1.57) than the traditional exercise (3.00, SD=1.41)(4.14, SD=1.77).

In the traditional exercise, participants frequently note that the realness of the fire contributed to the immersion (5 out of 7), but that the spacious layout and material of the space (4 out of 7) broke the immersion. 3 thought that in practice the scenarios wouldnt pan out as they would in the exercise. In the VR exercise, 5 note that immersion was enhanced by the ability to move through a complete cabin, and 3 noted the contribution of contextual audio and smoke effects. The main detractions from the immersion are the teleportation function, the limited space for free movement and the cable of the VR headset.

C. Performance and decisio making

While in both exercises participants felt a high urgency to act as best as they could (6.15, SD=1.07), on average they felt that their decisions and actions in the VR exercise less closely resemble reality (3.14, SD=1.57) than those in the traditional exercise (5.86, SD=0.69)

Fig. 7 displays the average assessment by the instructor of the participants performance. In the sample, participants typically made more mistakes in the VR exercise and were less successful in their task completion (3.86, SD=1.46) than in the traditional exercise (4.71, SD=1.60). Such mistakes included, for instance, forgetting skipping procedural steps (e.g. checking whether fire is successfully extinguished), trying to cool a lithium battery fire with ice (which works as an insulator) and trying to extinguish multiple fires simultaneously. Additionally, most participants failed to communicate clearly and correctly (or at all) in VR (3.86, SD=1.57) compared the traditional exercise (5.57, SD=1.51). Overall, participants displayed slightly better performance in the traditional exercise (5.05, SD=1.13) than in VR (4.21, SD=0.75) [Wilks Lambda=0.421, F(1, 5)=6.886, p=.05].

D. Heart rate

On average, participants had a slightly higher average heart rate during the VR exercise (105 bpm) than during the traditional exercise (95 bpm), but not significantly so [Wilks Lambda=.667, F(1,5)=2.492, p=.175]. Variability of the heart rate was slightly higher during the traditional exercise, but slow response times and sudden fluctuations in the measurements of the heart rate monitor make this metric uncertain: such inaccuracy is typical for physiological wristband sensors when used in motion [24]. While standard deviations of heart rate within subjects were similar, it seems that heart rates differ more between subjects in the VR exercise (SD=23.56) than in the traditional exercise (SD=7.79) Looking at the mean heart rate over the duration of the exercises (see fig. 8), the rates during acclimatization (first 90 seconds) are very similar, around 95. However, on average the VR exercise peaks about 15 beats per minute higher than the traditional exercise as the emergency scenario progresses.

	Mean (beats per minute)	SD (Within subject)	SD (Between subject)	Variability (Average change per second)
VR Exercise	105	14.9	23.56	0.67
Traditional Exercise	95	14.2	7.79	0.87

TABLE I

AVERAGE HEART RATE DATA OF PARTICIPANTS DURING VR EXERCISE AND TRADITIONAL EXERCISE

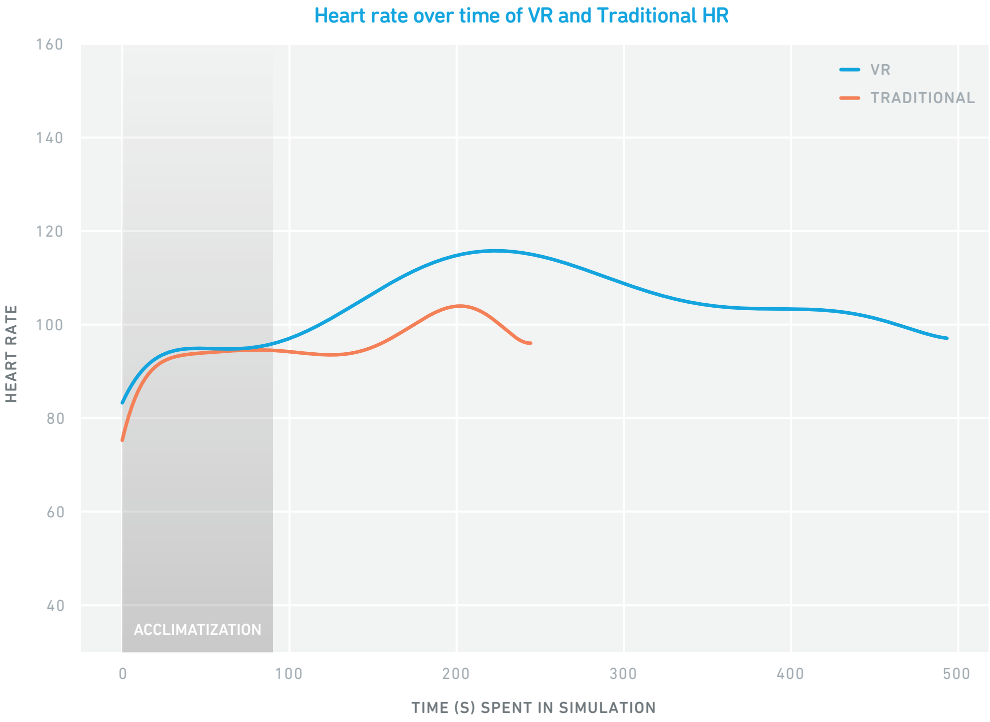

Fig. 8. Average heart rate response over time during exercises, smoothed using least squares polynomial fit (7th degree).

E. Relations between stress, presence and performance

The average heart rate shows some positive correlation with task load in this sample, but not significantly so (r=0.48, p=0.08). It does however significantly correlate with the stress/frustration/insecurity factor of the task load (r=0.58, p=0.03). Furthermore, the peak heart rate and task load are significantly correlated (r=0.56, p=0.04).

On average, a higher task load was generally perceived as more non-fictional (r=0.64, p=0.01), but correlates negatively to how representative participants thought their actions were (r=-0.69, p=0.01). However, the latter is likely a side-effect of the differences between the exercises, as in the traditional exercise task load and the representability of the actions display a somewhat opposite, albeit insignificant, connection (r=0.52, p=0.23).

The performance grades show little to no relation to heart rate and presence. A negative correlation between performance and task load (r=-0.34, p=0.23) may be present, but is insignificant in this sample. Looking at the performance criteria, the data shows that those that reported a high sense of presence typically more successfully followed procedures (r=0.58, p=0.03).

No significant correlation between presence and task load could be found in this sample (r=0.4, p=0.16), and a connection between presence and the average heart rate seems unlikely (r=0.15, p=0.61). However, both perceived tempo (r=0.89, p=0.01) and required effort (r=0.85, p=0.02) (aspects of task load) show a strong correlation to presence.

F. General observations and response

While presence ratings are somewhat similar between the exercises, participants displayed a high sense of immersion in VR: several forgot their physical surroundings and bumped into the walls at walking pace, and many expressed being disoriented and somewhat overwhelmed upon exiting VR (and seeing their actual surroundings). The VR experience also impacted the way participants processed information, particularly forgetting procedures, instructions and missing contextual information. For instance, every participant immediately forgot the location of the fire extinguisher once in VR, even though it is explicitly mentioned in the instructions (verbally and visually). The pattern of missing or mistaking contextual cues (e.g. searching erratically for the source of fire, but overlooking it) is somewhat in line with the tunnel vision effect of stress. In part these effects may be due to the novelty of VR to most participants. It was found that providing instructions through the headphones after the subject has entered the VR environment is more effective than verbal or written instructions prior, particularly for mastering the controls and interactions. However, even then several participants remained unresponsive in their actions or communication.

Another source of confusion for some participants are the inconsistencies between the virtual environment and the layout of actual aircrafts. For instance, not all equipment was positioned where it would be in an actual passenger aircraft. Additionally, the fire alarm sound caused some to look for the toilet (as this is the only location with a fire alarm and smoke detector in the cabin), although there was no toilet in the simulation.

IV. Discussion

The VR exercise showed significantly higher task load and somewhat lowered performance, no significant difference in presence and slightly higher average and peak heart rates. The latter pattern was not statistically significant, but this may be due to the limited sample size: the group of participants is likely too small to expose anything but the most obvious patterns through quantitative analysis. However, apparent differences between the simulation exercises can be found in the response to the factors that comprise the task load, performance and presence scores. For instance, the higher average heart rate in VR, despite a significantly lower required physical effort, suggests heightened arousal. The significantly higher reported stress and frustration are in line with this pattern.

As mentioned, the seeming inaccuracy of the heart rate data made it impossible to calculate heart rate variability with any degree of certainty. As this is a direct indicator of stress [25], rather than arousal, future research could provide more conclusive data by utilizing more accurate monitoring hardware. Additionally, a potential effect on the heart rate baseline, due to anticipation before the exercise, could not be excluded with the current setup: in future research a baseline recording should be made separate from the simulations.

It seems that, while the exercises dont significantly differ in their presence scores, the degrees of presence are achieved differently. In the traditional exercise, participants seem to feel more in control (perceived influence, protagonism) and report that the exercise enabled them to accurately follow procedures. Participants rated the VR exercise as less fictional and more authentic, and mentioned how a more complete context contributed to that.

The data does not tell much about the causality of the observed forgetfulness and inability to follow instructions and procedures amongst participants whilst in the VR simulation. This may point to an inability to deal with less predictable scenarios in a more holistic context, but may very well be due to a lack of familiarity with Virtual Reality and its interactions. The tendency of most participants to just extinguish the fires, and not follow other steps (communication, task division, cooling of batteries, checking) is reminiscent of the tunneling stress response, which is something to could be studied in future research. While three mentioned the progression of the emergency in the traditional exercise was unrealistic, on average participants claimed their actions in the exercise were more representative of how they would act in real-life. This could point to a believe that their ability to follow procedures would not be impaired much in real-life emergencies, or to how the inconsistencies and novelty of the VR exercise impaired them in following procedures. Steps to follow-up on this include the removal of inconsistencies in procedures and layout between the VR exercise and the actual aircraft and ensuring the participant is fully comfortable in using the VR system.

The value and applicability of VR in crew safety and security training will likely depend on the topic and didactical goal. Certain procedural steps, such as determining a source of heat with the back of your hand in case a source of smoke is observed or the techniques for constraining a unruly passenger, are too physically refined to accurately simulate with current VR technology. As such, drill training of specific, fixed interactions and procedures may be best done in a traditional manner, if feasible. VR does show significant promise for training for stress management and professional decision making in a unpredictable, stressful context or situation, due to its high variability and ability to immerse and induce stress. Collaboration and social behaviour are other aspects present in much of the training programmes of the CSST department, but somewhat lacking in the current VR exercise, although telepresence technologies (voice chat, virtual avatars) could provide a solution here.

Acknowledgment

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References

[1] Guillaume Alinier et al. “Effectiveness of intermediate-fidelity simulation training technology in undergraduate nursing education”. In: *Journal of advanced nursing* 54.3 (2006), pp. 359–369.

[2] Karen M Freeman et al. “A virtual reality patient simulation system for teaching emergency response skills to US Navy medical providers”. In: *Prehospital and Disaster medicine* 16.1 (2001), pp. 3–8.

[3] Luca Chittaro. “Passengers’ safety in aircraft evacuations: Employing serious games to educate and persuade”. In: *International Conference on Persuasive Technology*. Springer. 2012, pp. 215–226.

[4] N Dahlstrom et al. “Fidelity and validity of simulator training”. In: *Theoretical Issues in Ergonomics Science* 10.4 (2009), pp. 305–314.

[5] Robert M Yerkes and John D Dodson. “The relation of strength of stimulus to rapidity of habit-formation”. In: *Journal of comparative neurology* 18.5 (1908), pp. 459–482.

[6] Barbara K Burian, Immanuel Barshi, and Key Dismukes. “The challenge of aviation emergency and abnormal situations”. In: (2005).

[7] Adrian Harvey et al. “Impact of stress on resident performance in simulated trauma scenarios”. In: *Journal of Trauma and Acute Care Surgery* 72.2 (2012), pp. 497–503.

[8] Kathleen M Kowalski-Trakofler, Charles Vaught, and Ted Scharf. “Judgment and decision making under stress: an overview for emergency managers”. In: *International Journal of Emergency Management* 1.3 (2003), pp. 278–289.

[9] Choon Looi Bong et al. “Effects of simulation versus traditional tutorial-based training on physiologic stress levels among clinicians: a pilot study”. In: *Simulation in Healthcare* 5.5 (2010), pp. 272–278.

[10] Sandra Poeschl, Konstantin Wall, and Nicola Doering. “Integration of spatial sound in immersive virtual environments an experimental study on effects of spatial sound on presence”. In: *Virtual Reality (VR), 2013 IEEE*. IEEE. 2013, pp. 129–130.

[11] Sandra Poeschl and Nicola Doering. “Virtual speech anxiety training—Effects of simulation fidelity on user experience”. In: *Virtual Reality (VR), 2014 iEEE*. IEEE. 2014, pp. 105–106.

[12] Jean-Luc Lugrin et al. “Influence of avatar realism on stressful situation in VR”. In: *Virtual Reality (VR), 2015 IEEE*. IEEE. 2015, pp. 227–228.

[13] Yun Ling et al. “A meta-analysis on the relationship between self-reported presence and anxiety in virtual reality exposure therapy for anxiety disorders”. In: *PloS one* 9.5 (2014), e96144.

[14] Julia Diemer et al. “The impact of perception and presence on emotional reactions: a review of research in virtual reality”. In: *Frontiers in psychology* 6 (2015).

[15] Federica Pallavicini et al. “Virtual Reality Applications for Stress Management Training in the Military”. In: *Aerospace Medicine and Human Performance* 87.12 (2016), pp. 1021–1030.

[16] Mark B Powers and Paul MG Emmelkamp. “Virtual reality exposure therapy for anxiety disorders: A meta-analysis”. In: *Journal of anxiety disorders* 22.3 (2008), pp. 561–569.

[17] Shih-Ching Yeh et al. “A virtual iraq system for the treatment of combat-related posttraumatic stress disorder”. In: *Virtual Reality Conference, 2009. VR 2009. IEEE*. IEEE. 2009, pp. 163–170.

[18] Dwi Hartanto et al. “Controlling social stress in virtual reality environments”. In: *PloS one* 9.3 (2014), e92804.

[19] Mel Slater et al. “Bystander responses to a violent incident in an immersive virtual environment”. In: *PloS one* 8.1 (2013), e52766.

[20] A Dimov. *Combining virtual reality and physiological signals: lessons learnt*. Presentation. Mar. 2017.

[21] İsmet Eşer et al. “The effect of different body positions on blood pressure”. In: *Journal of clinical nursing* 16.1 (2007), pp. 137–140.

[22] Sandra G Hart and Lowell E Staveland. “Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research”. In: *Advances in psychology* 52 (1988), pp. 139–183.

[23] Yiannis Georgiou and Eleni A Kyza. “The development and validation of the ARI questionnaire: An instrument for measuring immersion in location-based augmented reality settings”. In: *International Journal of Human-Computer Studies* 98 (2017), pp. 24–37.

[24] Olaf Binsch, Thymen Wabeke, and Pierre Valk. “Comparison of three different physiological wristband sensor systems and their applicability for resilience-and work load monitoring”. In: *Wearable and Implantable Body Sensor Networks (BSN), 2016 IEEE 13th International Conference on*. IEEE. 2016, pp. 272–276.

[25] Julian F Thayer et al. “A meta-analysis of heart rate variability and neuroimaging studies: implications for heart rate variability as a marker of stress and health”. In: *Neuroscience & Biobehavioral Reviews* 36.2 (2012), pp. 747–756.

Pilot Study

A pilot research was executed with five students of the TU Delft as participants. The goal was to verify the test procedure, and discover unclarities or other aspect of the simulation that may prevent the yield of usable results.

Method

The five participants are first introduced to the virtual context in which they will enter, a passenger aircraft cabin with a number of interactive props lying around (fire extinguisher, phone, coffee can, can with ice cubes and laptop). Furthermore, the interactions enabled by the controllers, being teleportation over the walking lane, grabbing objects, using objects and interacting with the user interface, are explained.

At this point the wireless heart rate monitor (Mio Link) is mounted on the participant's wrist, and the recordings are started (heart rate and video). The participant puts on the VR headset (HTC Vive) and headphones, and grabs the controllers. The participant is instructed to move around and try out the interactions before starting the scenario (see **Fig.2**). This is done to the create a baseline where every participant at least knows how to interact with the system.

When the scenario is initiated, it starts with a normal situation (no emergency, pilot is heard announcing speaking to passengers over intercom). Over time, several fires are randomly started, smoke starts filling the cabin and the fire alarm is triggered. The participant can do a number of things, including notifying the cockpit / purser using the wall-mounted phones, use the fire extinguisher (see **Fig.1**) stored in the overhead compartment, or pour coffee over the fire. Furthermore, there is the possibility to pour ice cubes over a lithium fire, but this would only increase the fire's intensity.

When the participant succeeds in extinguishing all fire and shows no intention for further action, the simulation is terminated and recording is stopped.

Afterwards, the participant is asked to fill in the questionnaire on presence, stress and task load (see appendix B).

Results

The pilot research revealed a number of things:

- **Not intuitive for everyone:** Those who didn't have prior experience with VR took more time to get the hang of certain interactions. Especially the interaction of clicking a button in the floating dialogues was challenging, as it required two buttons to be pressed. Also, the grab buttons on the sides of the controllers were not immediately clear.
- **Teleporting is (too) easy:** some participants were afraid to move around freely in the constrained space, but all used teleportation as it was the quickest way to move around.
- **Communication is a challenge:** As the participant is closed of from reality both in vision and hearing, it is hard to communicate with them during the test. This lowered the pace of the test and broke the immersion.
- **Heart rate response:** Participants differed in heart rate and heart rate variability. Some showed an increase in heart rate as the emergency scenario started, while others' heart rate remained fairly consistent. Change in heart rate compared to a baseline is clearly the main topic of interest.
- **Immersive, but not seen as real:** The participants claimed to feel low to moderate levels of stress, moderate to

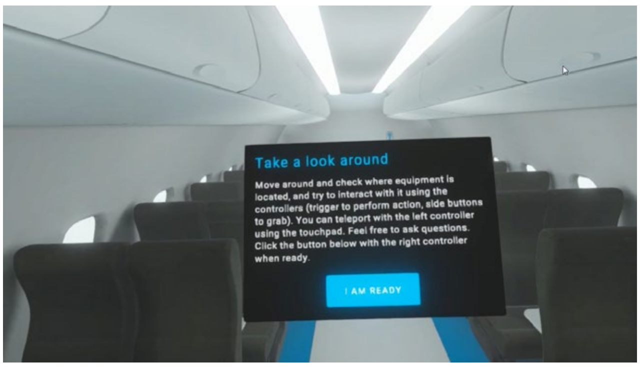

Fig.2 Introduction dialog in the pilot test.

Fig.1 Fire extinguisher used during research pilot

Fig.3 Participant in process of VR exercise during pilot research.

high levels of immersion and involvement, and low to moderate levels of being seen as reality.

- **Not that challenging:** The task of handling the emergency was seen as neither physically nor mentally challenging. This was perhaps due to the combination of an limitless fire extinguisher and the ability to teleport around quickly. However, not every participant handled the scenario properly, as some forgot to inform the cockpit or used ice cubes as a fire retardant.

Based on these findings, the following adjustments were made to the simulation:

- The text dialogues can be interacted with using a single button. Furthermore they have a less intrusive placement and make a sound to grab the user's attention
- The familiarization prior to the test will take place in a separate virtual scene, and require certain actions to be performed before entering the cabin and starting the scenario.
- An intercom functionality is added, allowing the observer / instructor to speak into the participant's headphones. The audio is spatialized to the intercom in the front of the cabin.
- The tasks are made more challenging, by having props malfunction or run out. Furthermore, fires are made less easy to extinguish, requiring better technique.

Furthermore, there are some procedural adjustments to be made:

- The screen should be included in the recording, as it is otherwise hard to assess what is happening. The start and end of capturing the screen, video and heart rate should be synchronized.
- Time to get acquainted with the context and interactions should be predefined, as should the time to deal with the emergency (as in real life an in cabin fire emergency should be dealt with within several minutes).

Appendix B: Questionnaire

A digital form was used to conduct the survey, hosted on typeform. It was provided in both English and Dutch. The content was as follows:

General questions

Wat is / will be your function at KLM?	
How many years of professional flight experience do you have (at KLM or elsewhere)?	
What is your age?	

Exercise related questions (for each exercise)

Type	Question / statement		1	2	3	4	5	6	7	
Taskload	**Mental:** How mentally demanding was the task?	Very low								Very much
	Physical: How physically demanding was the task?	Very low								Very much
	Tempo: How high was the pace of the task?	Very low								Very high
	Perceived Performance: How successful were you in accomplishing your task?	It went perfectly								It was a failure
	Effort: How hard did you have to work to accomplish your level of performance?	Very low effort								Very high effort
	Stress: How insecure, discouraged, irritated, stressed and / or annoyed were you?	Not at all								Very much
Presence	**Central Role:** I felt I was the main character in the activity, as the activity could be shaped according to my actions.	Fully disagree								Fully agree
	Realistic: I felt that I was in a highly realistic activity, in which I could hardly separate what was virtual or real.	Fully disagree								Fully agree
	Protagonist: During the activity, I felt that I was the protagonist.	Fully disagree								Fully agree
	Authentic: The activity felt so authentic that it made me think that the virtual characters/objects existed for real.	Fully disagree								Fully agree
	Experiential: The activity felt more as something that I was experiencing, rather than something I was just doing	Fully disagree								Fully agree
	Non-fictional: I felt that what I was experiencing was something real, instead of a fictional activity	Fully disagree								Fully agree

	Involved Interactions: I was so involved in the activity, that in some cases I wanted to interact with the virtual characters/objects directly.	Fully disagree								Fully agree
	Involved Impact: I was so involved, that I felt that my actions could affect the activity	Fully disagree								Fully agree
Learning goals	I think it was important to accomplish the task in the best possible manner.	Unimportant								Very important
	If the simulated situation had been real, I would have acted the same.	Fully disagree								Fully agree

Feedback: How would you describe the experience just now? What could be improved about the simulation?	
Immersion: Which elements of the simulation gave you the feeling that what was happening was real the most?	
Immersion: Which elements of the simulation broke the illusion of realism for you?	

Final roundup

Experience: How much experience do you have with fire fighting?	
Follow-up: Can we contact you for possible follow-up questions? Then please enter your email-address.	

Appendix C: Performance Assessment Form

Performance assessment to be filled in per exercise per participant. Performance score is an unweighted average of the criteria.

Criteria		1	2	3	4	5	6	7	
The participant followed procedures as much as was possible	Fully disagree								Fully agree
The participant communicated clearly and correctly	Fully disagree								Fully agree
The participant made correct or justifiable decisions	Fully disagree								Fully agree
The participant acted correctly and successfully	Fully disagree								Fully agree
The participant made few or no mistakes	Fully disagree								Fully agree
The participant displayed an adequate level of preparedness	Fully disagree								Fully agree
Average									

D. Requirements

THE FOLLOWING LIST IS A NON-EXHAUSTIVE COLLECTION OF REQUIREMENTS OF THE DIFFERENT COMPONENTS THE PROPOSED DESIGN ENTAILS.

Features that don't follow from these requirements typically relate to the criteria listed in the main report. Furthermore, it should be noted that the majority of these requirements couldn't be verified within the scope of the project, as they require a degree of implementation in practice to acquire sufficient data.

1. VR Simulation

1.1. The VR system should convincingly simulate an aircraft cabin context.

1.1.1. The virtual environment should be recognizable as a cabin, and have a layout reminiscent of the aircraft types flown by KLM.

1.1.2. The system should be able to simulate a set of emergency scenarios in a recognizable and ideally convincing manner, including both the critical events and their consequences on the context.

1.2. The environment should provide a degree of interactability, both related to simulated scenarios and the aircraft context.

1.2.1. The degree of interactability should be sufficient to support the major actions users would perform (depending on the context).

1.3. The VR simulation should be usable by the full extent of KLM's cabin personnel

1.3.1. It should accommodate for any impairment that personnel is allowed to have while holding their job position (e.g. wearing glasses).

1.3.2. The use of the simulation should not induce severe motion sickness within 10 minutes of consistent use in at least 99% of participants.

1.3.3. The interactions should be physically achievable by all users, including the ergonomics of peripherals and movement.

2. Simulation control

2.1. Trainers should be able to control the VR simulation.

2.1.1. The control should enable a degree of customization of the simulated scenario.

2.1.2. The control should provide ways to start, interrupt and end the simulation.

2.1.3. The control should be usable without programming or CAD knowledge, and require at most one-time instructions.

2.2. The control of the simulation should be centralized throughout the user journey of the simulation (preparation to evaluation).

2.3. Use of the control tool by the trainer should be possible within the time constraints set by the training programme.

2.4. Use of the control tool should not significantly impair the trainer in her / his ability to teach and communicate with students.

3. Evaluation and spectating

3.1. The system should record the performance of its users with metrics from which the quality of their performance can be derived or points of improvement can be yielded.

3.1.1. The recordings should be reviewable instantly after a simulation in a high fidelity.

3.1.2. The recordings should be available for review for a certain amount of time remotely.

3.1.3. The recordings should be protected from anyone other than the user and the staff of the CSST department, unless explicit permission is given to share.

3.2. If used the system is used in a context with bystanders, they should be able to observe what is going on in the virtual environment during a simulation.

4. System Architecture

4.1. The system should be largely location agnostic and easy to move and setup.

4.2. The system should be scaleable to work with multiple sets of hardware and concurrent users.

4.3. The system should be modular and extensible in terms of both software and hardware.

4.3.1. The software elements of the system should be remotely maintainable and updatable

4.3.2. The hardware components of the system should be individually repairable, replaceable or upgradeable on short notice for the coming decade.

4.4. The system and physical space should ensure peripherals are ready to use and charged at practically all times.

E. Cost Calculation

A QUICK ESTIMATION OF THE REQUIRED INVESTMENTS FOR DEVELOPMENT AND RUNNING OF THE PROPOSED SYSTEM WAS MADE. IT ASSUMES AN EXTERNAL AGENCY IS HIRED TO DO THE MAJORITY OF THE DESIGN AND DEVELOPMENT WORK, AND THAT A MVP APPROACH IS TAKEN.

Variables

Variable	Value	Source
Group size	15	
Simultaneous Users	2	
Spectator Views	1	
Developer cost per day	800	
Overhead %	25	

Hardware Resources

Item	Quantity	Price per Unit	Total Price	Source
HTC Vive	2	€ 899,00	€ 1.798,00	https://tweakers.net/pricewatch/480416/htc-vive.html
High-End PCs	3	€ 2.000,00	€ 6.000,00	https://tweakers.net/pricewatch/728385/hp-omen-870-245nd.html
Wireless HMD transmitter	2	€ 200,00	€ 400,00	https://uploadvr.com/htc-vive-wireless-kit/
Isolating Headphones	2	€ 150,00	€ 300,00	
3D printed charging mount	2	€ 60,00	€ 120,00	PETG print from 3DHubs
Router	1	€ 120,00	€ 120,00	https://tweakers.net/pricewatch/350946/netgear-nighthawk-r7000-ac1900-smart-wifi-router.html
TV screens	1	€ 900,00	€ 900,00	
Foam wall panels / tiles	192	€ 2,00	€ 384,00	http://bit.ly/2uCtSKW http://bit.ly/2uGtHdl
USB NFC reader (check-in)	2	€ 57,00	€ 114,00	https://www.bol.com/nl/p/nfc-reader-writer/9200000047154333/

Yearly running costs

Item	Cost per year	Explanation	Source
Further developement	€ 4.000,00	5 days of development	
Hardware replacements	€ 1.520,40	15% hardware replacement / upgrade per year	
System maintenance	€ 4.000,00	5 days of maintenance activities	
Server for realtime multiplayer	€ 0,00	Photon is free 20 concurrent users	https://www.photonengine.com/en-US/PUN/Pricing#plan-20
Server database and storage	€ 400,00	Depends on internal infrastructure, but overall storage is cheap	

Yearly running costs

Section	Task	Days	Cost	Source
Simulation	Asset Creation / sourcing	7	€ 5.600,00	
	Animation	2	€ 1.600,00	
	VR interaction system	5	€ 4.000,00	
	Game logic	7	€ 5.600,00	
	Sound design / sourcing	2	€ 1.600,00	
	Level design	2	€ 1.600,00	
	Network multiplayer + spectation	4	€ 3.200,00	
	App integration / connectivity	2	€ 1.600,00	
	Recording and storing video	2	€ 1.600,00	
	Testing and debugging	5	€ 4.000,00	
Simulation Control App	Interfacing with VR Simulation	2	€ 1.600,00	
	Scenario creation flow	2	€ 1.600,00	
	Real-time control flow	3	€ 2.400,00	
	Evaluation / playback flow	2	€ 1.600,00	
	Remainder UI	2	€ 1.600,00	
	Network storage integration	2	€ 1.600,00	
	Authentication	1	€ 800,00	
	Testing and debugging	3	€ 2.400,00	
VR Room construction	Space design	3	€ 2.400,00	
	Interior construction	4	€ 3.200,00	

Calculated estimates

Cost Calculation	Gross	With overhead
Resources Cost	€ 10.136,00	€ 12.670,00
Development Cost	€ 49.600,00	€ 62.000,00
Total fixed cost	€ 59.736,00	€ 74.670,00
Running cost per year	€ 9.920,40	€ 12.400,50

F. Stakeholder Validation Interviews

SEVEN STAKEHOLDER (CSST MANAGER, TWO PEOPLE INVOLVED WITH KLM INNOVATION PROJECT, AND FOUR TRAINERS RESPECTIVELY) GO TO TRY OUT THE PROPOSED DESIGN AND WERE INTERVIEWED ON THEIR VIEWS AND IDEAS.

Learning Goals

What does the design, in your opinion, offer over current training modules?

- **Roel van Leeuwen:** The higher scalability and adaptability. The additional surroundings respond better to what you are doing. The environment feels (socially) safer to make mistakes. Sensorially, the VR simulation would be closer to real-life.

- **Sam Krouwer:** The real surroundings and passengers. That you can create scenarios, and involve actualities from the news and personal stories in the teaching. It also becomes cheaper to implement new scenarios.

- **Chris Koomen:** The traditional training (in the fire room) has almost nothing to do with an aircraft in comparison. The app makes it very easy to edit scenarios, and add an element of unpredictability and surprise. It can also make the training more goal-focused.

- **Femke Hofstra:** You really feel like you are in there, that you really have to do something. You immediately perceive the psychological factors. Like, 'oh there is too much fire, I won't be able to deal with this'.

- **Mirjam Boerop:** It is really realistic, you are immediately immersed.

- **Crystel Diepeveen:** I think it is a good way to close you of for a moment from what is happening around you, and be truly occupied with the exercise that you are doing. In the traditional training you are always conscious of the spectators and the fact it is a training. The value also depends on how far you can go in programming things. Like for instance, in real life you might decide to throw a blanket over a fire to extinguish it. If you implement many of those things, that gives users the ability to really choose how they are going to extinguish that fire.

- **Sander van Geffen:** You could get to experience things you normally don't, like the passengers, the smoke development, a feeling of asphyxiation, basically anything that could normally happen. You can also more realistically do ABC procedures. It would also be less hard to ask for people to imagine what it would be like, because they can just be subjected to it. In many training modules people say they would do it differently in real life, but here that excuse doesn't work. It is a good way to train decision making ability. In traditional training you just have very limited choices. I also think it valuable that you can look back afterwards.

What impact do you think the simulation and system will have on the attitude of training participants toward the training and safety in general?

- **Roel van Leeuwen:** Firstly, it adds a not unimportant 'fun-factor' to the training day, potentially increasing excitement. It increases the time available for effective practice and participants will likely better understand risks, and take consequently take the training and safety more seriously.

- **Sam Krouwer:** When I participated in a training once, I clearly saw most participants just were there because they had to. With this, motivation will likely be increased because the training becomes more engaging. Perhaps a bit unrelated, but I think the gap between digitalization and the working environment will be reduced with this.

- **Chris Koomen:** I think it will create an increased awareness, in a more intense way.

- **Femke Hofstra:** I think most will be open to it, think it is very cool and professional, and be triggered to do a lot in there. But there will also be a certain group of people more skeptical, thinking 'why do we have to do it this way?'. This is most a generational gap I think [specially related to VR as technology].

- **Mirjam Boerop:** I think it is very professional and up-to-date with the times. With that I think it will add to the overall safety, because it is so realistic. In current simulations things always happen in a best-case scenario, but here you can create scenarios that can really happen on board. People hyperventilating when there is a fire, etc. You start taking into account multiple factors.

- **Crystel Diepeveen:** It will be pretty challenging to implement this in training. Maybe a initial training participants, who are a bit younger, will be very open to using this. But that may be a bit harder with tri-yearly recurrent participants with 30 years of flight experience but no iPad experience. I think you should show off the VR with a random scenario at a place like the crew center [Schiphol], to give the CAs the feeling of using VR outside of the training context.

- **Sander van Geffen:** I think it will split the participants between people who think it is awesome, and people (those without iPad experience) that are more skeptical. They will not see the value that much. Although, experiencing VR for the first time is a pretty sensational experience. Maybe that will pull them over the line. Especially if it is simple to control, which it in fact currently already is. Maybe you need to start the simulation with one minute in a blank room with a few things, like the fire extinguisher or a door, where you get to experience 'this way I open a door', 'this way I pick something up'. Then they know the functions and can enter the cabin.

What does, in your view, the design do to the role of the trainer? What could be the benefits and what could be the downsides?

- **Roel van Leeuwen:** In this system, the trainer must be more dynamic and be adaptive to changing circumstances. While it does give them more ways to control the simulation over, say, the current fire fighting training, this also adds to their responsibility. In some cases this added responsibility will not be appreciated.

- **Sam Krouwer:** The trainer will have more flexibility and a larger toolset to teach with.

- **Chris Koomen:** The trainer becomes more of a coach, who guides and facilitates what happens. But you would be asking a bit more from them that way.

- **Femke Hofstra:** I don't see it as being replaced, I see it as an addition and I would enjoy using it and see the added value. Trainers do have to have that motivation however. [...]. I think about 80% of the trainers will like to use the of the app. Especially when you can play into someones personal experiences. But trainers need to be trained on how they can use it properly.

- **Mirjam Boerop:** It becomes really facilitating, and I think most trainers would like that role. I do think it can be quite intense for the CAs, that you really hear the alarm sounds. But I think it is very cool we can tell people that we make things like these, and that it is really a significant addition.

- **Crystel Diepeveen:** It will be a bit different that you have to do two things at once, like control the simulation and observe what the participants do. In the beginning, that might be a bit of a struggle. But the increased evaluation will be of value to the participants. Now you push 14 participants through a simulation, then afterwards you can't remember who did what, so you just throw general feedback at the group while maybe 8 of them don't recognize what you talk about.

- **Sander van Geffen:** Trainers will become more reflective. In the traditional training participants know what to expect (especially the recurrents), but here you can, as a trainer, really integrate different parts of the programme. Like you said, something like a medical emergency and fire fighting could really happen simultaneously on board. [It is challenging to] split your attention between those things. Also, conventionally we mostly train things that are described in the manual, but there are of course a lot of things that could happen not described in there. We also have to think about that, and that involves a bit of common sense. The customizability is also a way to give everyone a personal experience.

In what ways would the simulation influence the ability of personnel to perform in critical situations?

- **Roel van Leeuwen:** This is hard to be conclusive about, given the intentionally low 'n' in your research. But I am convinced it can take away insecurity factors amongst initial training participants. If it is sufficiently well developed, I think there will be a pivot-point from recurrent participants thinking 'this is a game' to 'I can really learn something from this'. Verbal evaluation and discussion are really important for making people learn.

- **Sam Krouwer:** On the short term, it will mainly show what kind of things can happen, what scenarios are possible. It will also introduce use of digital learning tools to CAs. But on the long term I believe this will become more realistic in every way than the current training. In practice, I think the VR is a better preparation for the unpredictability of real scenarios. You really don't know what is going to happen, just like real-life.

- **Femke Hofstra:** I think the training for actually using an extinguisher will always remain physical, but to deal with task division and keeping an overview during an emergency, especially if you can do an ABC procedure with three people, this system makes a significant addition. Responding to the situation, and giving each other feedback.

- **Mirjam Boerop:** I think you will quickly see how people behave in this simulation, and know who can keep others calm and think clearly. This level of realism is not something we can currently train, especially that you can add something to it unexpectedly.

General feedback

What are your general impressions of the proposed design?

- **Roel van Leeuwen:** The app, even though it was not in the original scope, is perhaps the most important aspect to making the system usable. The collaborative functionalities, even though we couldn't test them, might be a bit too much for CAs. I suspect just using the controls will require most of their attention. The controls have improved significantly since the previous version however.

- **Sam Krouwer:** I think that the multiplayer functionality is really valuable, although we didn't get to see it today. For implementation I would go even further in making it feel like a real airplane, for instance by placing a trolley in the middle of the walking lane. Like, how would you deal with that?

What response did the virtual passengers evoke in you?

- **Roel van Leeuwen:** The sounds they make really add to the experience. Their behaviour can be improved, be more realistic. Ideally, the behaviour of the passengers would actually play a role in the scenarios.

- **Sam Krouwer:** I think the current state is sufficient for a MVP, especially because there is not really a market standard for something like that. You can spend millions on making it really realistic, but then some third party may release an alternative at any time. However, some of the basic behaviour could be better, some passengers just sat in the fire.

- **Chris Koomen:** To make it actually realistic, the costs would be enormous.

- **Femke Hofstra:** You couldn't do anything with them. If there is a fire, it would make more sense for them to walk away from it. I would like to be able to grab them, or just tap them to make them disappear or something.

- **Mirjam Boerop:** You hear them talking, I thought that was quite realistic.

- **Crystel Diepeveen:** I think it would be especially valuable if you can do something with them, like get them out of the way [in case of emergency]. In case of fire there are really only a few things to do passengers: get them out of the way and let them duck.

- **Sander van Geffen:** I am in favour of it, it puts life into it. Although I do think technologically their behaviour should be a bit more developed. Maybe you can also involve that they might be in the way when they stand up in the walking lane. I think there is quite a discussion to be had here.

Where the interaction patterns engaging and intuitive upon first use and after practicing?

- **Roel van Leeuwen:** The controls have improved a lot since the last time I used them, but ergonomically it is still hard to hold the controllers and press the buttons on the side at the same time.
- **Sam Krouwer:** For me, it wasn't immediately intuitive. On a Playstation you would use the trigger button to grab something. Also it was a bit too precise to really put the controller in the correct position to grab something. I would increase the size of the zone from which you can grab.
- **Chris Koomen:** I would use the trigger button for grabbing objects, but the teleportation mechanism works nicely. The physical simulation of the objects actually adds to the learning value. Like, it made me understand that you should grab them in a certain way to not bump into things.
- **Femke Hofstra:** The second time was much easier for me. And also to be able to recognize the type of airplane, then know where the extinguisher is because of that, will be really helpful.
- **Mirjam Boerop:** There was this one passenger that sat as if he was having some issues, so I went up to him to ask how he was doing. I would like to be able to ask question.
- **Crystel Diepeveen:** At first I was not sure how sensitive it would be, so it took me a moment to get the hang of it. But I think, knowing that last Monday I had to teach a CA how to make screen shots on her iPad, it might be more challenging for some.
- **Sander van Geffen:** I don't think it is hard to use, but I have used VR a bit before. Maybe it could ergonomically be simpler, that you click one to grab something, then click again to drop it, in stead of holding the button.

What did you expect to be possible, and wasn't? And vice-versa?

- **Sam Krouwer:** No, I was actually quite surprised that everything worked. Only that the cable was a bit in the way sometimes made me feel restricted.
- **Femke Hofstra:** A lot more was possible than I expected, that you could open all the cupboards and overhead compartments. Also that you can duck when there is smoke, to stay low.
- **Mirjam Boerop:** Things like you telling me to try pouring the coffee, but there was no cup. The only other thing is having any type of interaction with the passengers, that is something I would expect.
- **Crystel Diepeveen:** For the most part not. Just some things I already mentioned, like the ability to tap water or throw a blanket over a fire. Making the cabin complete would really be selling point. I do understand that you wouldn't replicate every detail, as long as it is a bit complete and everything is in the correct place.
- **Sander van Geffen:** No really, for me it worked as I expected. But I do think it is necessary to exactly replicate the interior of the aircraft. This will give the participants also more familiarity with their surroundings.

What would you change in order to make it better or more fitting to the department?

- **Roel van Leeuwen:** A more in-depth development of scenarios is necessary, and we need to ask what learning goals we want to serve with that. What do you aim for with the time line? Otherwise, for actual use it is very important that the virtual aircraft is effectively completely accurate.
- **Sam Krouwer:** Do more validation with a larger, more diverse group of CAs (also the old ones). Also talk to the trainers.
- **Crystel Diepeveen:** [In this testing environment] you have the problem that it is not an empty space. But I think

would work well in a dedicated empty space.

- **Sander van Geffen:** Mostly the controllers, and perhaps their configuration. And I would like a bit more walking area, or at least that the space is empty apart from maybe some cushions on the wall (to prevent bumping your head).

Trainer Questions

Do you see the system fitting with your teaching programme and style?

- **Femke Hofstra:** For me it would be very fitting, because I enjoy on-the-job training and like to involve current affairs in it. If I see that someone is very good with medical procedures, but needs more training for fire fighting, I would really like to make the training more personal for them.
- **Mirjam Boerop:** I don't do initial training, but I do think it is also applicable in recurrent training. It is also a good tool for tailoring it personally for the participants.
- **Crystel Diepeveen:** I think it is an addition, but not a replacement of the physical training. I am in favour of it though, and see more and more is possible. I just had those [VR] glasses on, and immediately had like 10 ideas of what could be possible. Like a ditching [crash on water, raft] or cargo fire. But I am quite curious how you would do it with a full class of participants, if only 3 people can be in VR at the time.
- **Sander van Geffen:** [In response to Crystel] The other participants can spectate what is going on via the display. They can learn from the personally. Or you can give them the task to write down a 'tip' and a 'top' [feedback method], maybe in pairs of two.

What do you think would be the impact of the approach the design takes towards evaluation? Will this work?

- **Femke Hofstra:** It is something to make time for, but there is real added value in reviewing it visually. But I do think some participants will blame their performance on the VR a bit.
- In the simulation control app, how did you perceive the following aspects for frequent use: Usability, level of control, clarity of the provided information, efficiency
- **Femke Hofstra:** [Femke used the app properly without instruction]. I do think there is enough control because you can play existing scenarios but also create your own. I was also able to follow what is going on from the map, but I don't think the real-time triggers really have really high priority.
- **Mirjam Boerop:** Femke is a bit more familiar with technology than I am, but I also see myself able to use it. I thought the information was presented clearly, and think it is useful to be able to communicate and send hints (highlights).
- **Crystel Diepeveen:** In my perception it looked simple to use. What I like was that I could specify what type of fire and where in the cabin it would take place.
- **Sander van Geffen:** I gives you a lot of possibilities, that you can even make a custom scenario. And I don't think it was harder than picking a configuration at a door trainer. The map was useful, I would even want to use it in the evaluation, like 'where were you standing when that happened?'.

What additional abilities and control over the simulation would you want?

- **Femke Hofstra:** How would you do the serving safety? Wouldn't that require you to communicate to passengers?
- **Mirjam Boerop:** Could you also do CPR as part of the scenario? Or just fetch the AED? But some things, like a door drill, you would always need to do physically.
- **Crystel Diepeveen:** I think it is good to start with a basic implementation, and then let the trainers say what else they need and what they can deal with.

- **Sander van Geffen:** Really we would just need to have this to our disposal for a week or so, and just play with it. Then you would really come up with a lot of ideas and discussions.

What do you imagine future developments would be like with this system?

- **Mirjam Boerop:** I think the developments go really fast. I think it is not a full replacement, but a great addition to our toolbelt at the department.

- **Crystel Diepeveen:** I think VR, as well as AR, can work well in combining parts of the training. [On the idea of making it available at airports] I do think it would be expensive to rent the spaces and make them available at all times. And you would likely rely on peoples intrinsic motivation to use it.

- **Sander van Geffen:** I don't think it would shorten the training per se, likely even make it a bit longer. [On the idea of making it available at airports] I do think it is good to spread training more throughout the year, but you run the risk that people start developing their own standards if they train without supervision.

CSST Management Questions

Does the estimated 75k for MVP and 12.5k yearly running and expansion costs, in your opinion, weigh up to the value proposition

- **Roel van Leeuwen:** The costs are certainly acceptable, but I suspect it is somewhat on the low end. I expect there to be additional unaccounted costs.

The budget is largely based in development costs. What level of development and polish would you expect, and how would you alter the budget accordingly?

- **Roel van Leeuwen:** For application in recurrent training, a high degree of realism is necessary. The requirements for initial training are lower [perhaps more suitable for MVP]. The environment has to be realistic in the MVP, but it doesn't have to be feature complete.

Would the department be interested in seeking revenue streams, for instance by renting facilities or the software to other airlines?

- **Roel van Leeuwen:** We would be interested, but this depends on the response of the 'training facilities' department. They might be a bit more hesitant to pursue such a model. Of course it could be shared with daughter airlines (Transavia, Martinair), and I think mid-sized airlines (SAS, MKB, Fin Air) would be interested and lack the resources internally to make it themselves. Large airlines would be interested, but more likely build their own.

On the short term, the design is not intended as a replacement for mandatory parts of the training. Do you think it is feasible to replace certain parts with regulatory approval in the future?

- **Roel van Leeuwen:** I actually think it can replace some parts in the initial training. Overall, there are some small parts regulation mandates that could easily be done in VR, although it will always be mandatory to practice use of the physical emergency slide. It could also reduce the reliance on physical hardware (e.g. the theoretical examination that takes place with door trainers).

Crew Experience Questions

How do think this design could connect to ongoing VR experiments at KLM?

- **Sam Krouwer:** It could be applied at Ground Services and Service Training.

- **Chris Koomen:** It could be reused for technical training, or as a way to interactively visualize and customize the interior of aircrafts.

What do you think should be the approach towards implementing this type of system (VR or AR) within KLM?

- **Sam Krouwer:** At Crew Experience (at Schiphol airport itself) we have crew stopping by between flights all the time. They are perfect for doing some co-creation with.

G. Code Review

> THE CODE FOR BOTH THE VR SIMULATION PROTOTYPE AND THE SIMULATION CONTROL APP IS STORED IN A PRIVATE GIT REPOSITORY AT HTTPS://GITHUB.COM/TIMMEVANDERMEER/KLM-CSST-VR-GRADUATION.

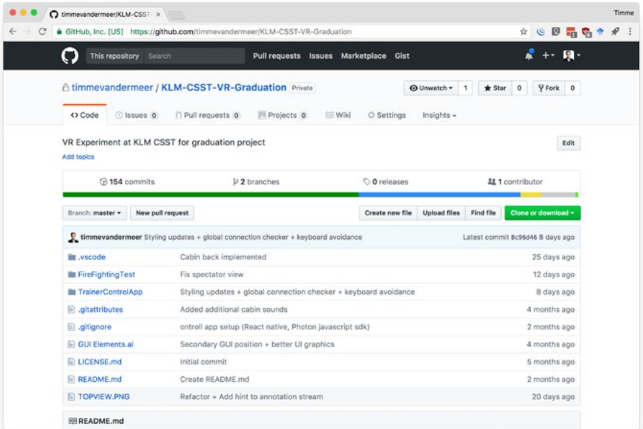

Fig.4 Repository on Github

This repository is version-managed, meaning all past iterations of the code are available. Access to the repository can be requested by emailing timmevandermeer@gmail.com.

VR Simulation

Folder `./VR-Simulation`

This folder contains a Unity 5.5.2 project, including all 3rd party libraries, code, sounds and 2D / 3D assets used in the simulation (stored in the '`Assets`' subfolders). The project and simulation can be run by opening the folder in Unity 5.5.2. The cabin environment is available in the '`ObjectCaster`' scene in the '`Scenes`' subfolder.

Prerequisites

- ☐ Unity 3D 5.5.2
- ☐ Steam VR (For VR use, optional)

Simulation Control App

Folder `./SimulationControlApp`

This folder contains a React Native project, fully compatible with iOS (iPad, primarily), and almost fully compatible with Android. React Native uses a common Javascript interfacing layer (see '`src`' folder) on top of native code ('`ios`' and '`android`' folders), to structure and style the user interface and run application logic. It retains near-native performance, but dramatically speeds up development.

Prerequisites

- ☐ Node.js
- ☐ Xcode (For iOS builds, optional)
- ☐ Android SDK (For Android builds)

Instructions

- ☐ Navigate to the folder in a shell of your choosing (cmd.exe, powershell, bash, etc.)
- ☐ Run `npm install -g react-native-cli` to install React Native on your computer
- ☐ Run `npm install` to install dependencies of the application to the folder
- ☐ Run `react-native link` to link the native libraries to the react-native application. This may require some manual fixes
- ☐ Run `react-native run-ios` or `react-native run-android` to run the iOS and Android apps respectively, either on a simulator or on a physically attached device. The application can also be run by opening the project in Xcode or Android Studio.