GRADUATION PROJECT IPD

IMMERSIVE SAFETY & SECURITY TRAINING

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Executive Summary

THIS PROJECT EXPLORES THE POTENTIAL OF VIRTUAL REALITY (VR) AS A TRAINING TOOL AT THE CREW SAFETY & SECURITY TRAINING (CSST) DEPARTMENT OF THE ROYAL DUTCH AIRLINES (KLM).

WITH A RESEARCH AND PROTOTYPE DRIVEN APPROACH, A VR SIMULATION AND ITS INTEGRATION INTO THE TRAINING PROGRAMME ARE DESIGNED. THIS SIMULATION AIMS TO IMPROVE STRESS RESILIENCE AND DECISION MAKING SKILLS OF CABIN ATTENDANTS (CA), AND CREATE MORE PERSONALLY RELEVANT TRAINING.

Context & Case

The CSST department facilitates training to both cabin crew and flight crew on safety and security related theory and procedures throughout and surrounding the flight (in which this project focuses on the tasks of CAs). Interactive simulators are among the primary tools to convey knowledge and allow trainees to practice with a set of scenarios, from CPR and pre-flight checks to fire fighting and emergency cabin evacuations.

However, for practical reasons these simulations typically make large abstractions from reality, resulting in participants that are continuously aware that the simulation is not real. Furthermore, there is a concern that the limited versatility of these simulations makes the recurrent training programme predictable, less engaging and personally relevant over the years.

The department sees potential to improve upon this situation by incorporating immersive technologies like virtual reality and augmented reality. This project, which took place from February to September 2017, intends to evaluate this potential, and envisions how these technologies can be implemented at the department.

Fig.1 KLM employee with HTC Vive

Research

Based on a context- and stakeholder analysis, a set of learning and development goals that the VR simulation should support is determined: professional decision making skill, personally tailored training, improved tools for evaluation and professional attitude.

Particularly professional decision making in a stressful, critical situation seems an important skill to have.
Current training is focused on fixed procedures, but these procedures often only cover a small percentage of real-world emergencies (Burian et al., 2005). Additionally, the stress emergencies may induce (from their context or potential consequences) influences behaviour, and can be detrimental to performance. Thus, the hypothesis is formed that current training practice does not adequately prepare for urgency, stress and unpredictability of cabin emergencies, and that a VR simulation could be a closer approximation of reality in this sense.

To test this hypothesis, a user study was conducted with CAs, comparing current in-cabin fire fighting training to a VR alternative. This preliminary design includes a full-scale interactive cabin environment, with multiple possible courses of action and contextual effects such as spatial sound and obscuring smoke. The study compares the two methods in regards to stress (task load, heart rate), performance and presence. The results signify an increase in experienced stress, heart rate and task load in VR, as well as a worsened performance: the study's participants tended to make more procedural mistakes and communicated poorly when in the VR environment. A separate paper was written on the study, which is available in appendix C.

Fig.2 Simulation Control app

Design Proposal

One of the research findings is that VR is not as effective as physical simulators at training the nuances of (physical) interactions in procedures. Rather, its potential lies creating a virtual environment where a diverse set of events can occur, resulting in more complex and unpredictable scenarios. The simulation utilizes a room-scale VR system, enabling users to interact and move through natural motion.

Trainers are enabled to create more personally relevant training, by easily creating custom scenarios using the 'Simulation Control' companion app, which also provides them with ways to control the simulation and communicate with participants that are immersed in the virtual environment.

Using a real-time multiplayer integration, the virtual environment can be shared my multiple users and spectators simultaneously. While VR is typically isolating a user from its environment (and vice-versa), this enables both collaboration (an important facet of most procedures) and shared evaluation. The proposed design envisions between 1 and 3 participants in VR simultaneously, while the trainer and remainder of participants spectate. Whilst spectating, Simulation Control allows the trainer (and spectators) to bookmark moments of interest. As all performances in VR are recorded and stored on an internal server, these moments can easily be revisited in the evaluation afterwards or at any later date.

Evaluation and next steps

The final design proposition was validated with diverse stakeholders by letting them experience the integrated VR experience and the Simulation Control app, to a positive response. Not only was the value proposition perceived, experiencing the prototypes inspired a host of new ideas (particularly among trainers).

It is advised to take a Minimum Viable Product (MVP) approach towards implementation, as this lowers the risk of investment and as VR is, by its software nature, easy to iterate upon. Furthermore, it is the only viable way of a short-term implementation (within 2018) of the proposed design. This MVP should successfully function as a training tool and contains an implementation of each component, but can limit the implementation of different scenarios and environments. Assuming an external agency is hired for the majority of the implementation, the MVP is estimated to cost around 13k in hardware and 62k for development and design. It is then proposed to continue adding functionality and content over subsequent years, with an estimated yearly running cost of 12k.

Finally, it is worth considering turning the system progressively into a platform, for instance by incorporating augmented reality or sharing a base system between the training facilities within KLM. On a longer term the simulation can also enable training remotely throughout the year (e.g. in select hotels or airports).

In general, while it is unlikely that VR simulation can fully replace the physical simulators regulation mandates, it does provide significant added value to the completeness of the training programme (stress resilience and decision making), in addition to providing means to create more engaging and versatile training days.

CONTENTS

Introduction

THE DEPARTMENT OF CREW SAFETY AND SECURITY TRAINING (CSST) OF THE ROYAL DUTCH AIRLINES (KLM) TRAINS AND RETRAINS THE CREW OF ITS FLIGHTS, COMPRISING CABIN (9000+) AND COCKPIT (~2500) PERSONNEL, FOR SAFETY AND SECURITY RELATED CONDITIONS, FROM PREVENTION TO EMERGENCY RESPONSE.

Safety and security topics are covered through lectures, group activities, and interactive simulations. These simulations exist typically in the form of hardware installations on the ground that cover one or several procedures or scenarios in a certain part of an aircraft. For instance, firefighting training in fire proof cabin replicas, training for emergency aircraft evacuation in a full scale cabin simulator, as well as role-played hijacking scenarios.

These training programmes are present to comply to aviation safety regulations from organizations and governments, but also to adequately prepare crew members for real-life emergency scenarios.

Case

It is challenging to incorporate all potentially relevant aspects of a critical situation, including factors like stress, panic, unpredictable risk and contextual cues, in an interactive simulation. Limitations in resources, be it financially, physically or practically, result in a set of simulations at CSST that fall short in terms of immersion and realism. A training more representative of reality could potentially serve as both a better evaluation of real-world performance and improved familiarization with real-world emergencies.

Technologies like Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) have recently risen in popularity, accessibility and fidelity, and are often cited as means of creating 'immersive experiences'. While often associated with gaming, applications for businesses and industry are rapidly developed, with a combined projected market size reaching 120 Billion USD by 2020 (from around 4 Billion USD in 2016) (Digi-Capital, 2016). In the case of simulations and training, these technologies have a number of potential benefits that KLM is interested in:

- **Virtually limitless:** virtual content can dynamically be changed and is in many ways not limited by the laws of nature, making it possible to simulate 'everything'.
- **Portable and scalable:** with limited required hardware, simulation setups can be made easily accessible to crew members around the world.
- **Flexible and tailored:** content in VR / AR / MR can be adjusted at any time, giving CSST more granular control of its training programmes.
- **Experiential learning:** if the user feels 'present' and immersed in the simulation, she / he can experience extreme emergency scenarios that would otherwise not be safe to simulate.

As such, the assignment from KLM is to research the potential applications of these ‘immersive technologies’ at CSST, in the simulation of cabin safety and security scenarios. This project coincides with a renovation of the CSST facilities, where digitalization and flexibility, for AR and VR in particular, are spear points.

Structure

This report starts with an analysis of the context, stakeholders and recent industry developments. This is done using literature research, field research and expert interviews. In the simulation training section different means, uses and potential shortcomings of simulations are evaluated.

The findings of both analyses yield a further specification of the scope (approach, context and learning goals), as well as several questions regarding stress, professional decision making and abstraction in simulation training. The latter are discussed in the research section, which reports upon a performed user study where traditional CSST simulation training is compared to a VR alternative. The VR simulation is in this case a preliminary design and prototype, of which the development is documented in the same section.

The design section starts with the formulation of design goals, based on both the defined scope and the findings from the research. To explore what the implementation of VR should entail as a system, a user journey is envisioned. Furthermore, revisions on the simulation design are made, the system architecture is defined and a business case is made.

Finally, the design is validated with stakeholders, and proposed next steps for integration and further development are listed.

Appendices, to which the report occasionally refers, are available in a separate document.

Project Structure

THE PROJECT COMPRISES FIVE PHASES, AND SPANS FROM FEBRUARY TO SEPTEMBER 2017.

Goal forming

The different facets of the case are explored through participation in the training programme, interviews, stakeholder analysis and field research. This phase serves to become aware of the context, formulate project goals and define the scope: who to target, which goals to serve and what context to focus on, in both the research phase and the final design.

Research

The research phase is parallel to the goal forming and concepts phases. This is done because the research takes a long time to setup and execute, but relies on the scope definition from the first phase and scenarios from the concept phase, and the findings serve as way of selecting the best solutions in the concepts phase. The research phase includes both literature research and a user study on presence, stress and performance in simulation facilitated by immersive technologies versus traditional simulation.

Concepts

The concepts phase starts with ideation on how simulations could be shaped to provide a meaningful improvement to the quality of the training (according to the criteria set in the scope), and what roles different technologies and 'ingredients' of the simulation could play in that. A potent but feasible direction is quickly selected to serve as the focus for the user study. Once the study has yielded results, the scope is opened up for conceptualization for how the design should behave as a larger integrated system.

Development

Ultimately the aim is to make a proposal that is demonstrably suited and valuable for the context of CSST and KLM as a whole. Therefore, the design should be sufficiently detailed and comprehensive, including aspects like a user journey and business case. Furthermore, to be able to validate the proposal, it should be sufficiently prototyped to be effectively communicated to stakeholders.

Finalization

Because there is a diverse set of stakeholders to the project, and as the proposition of VR / AR is still quite radical in the context, it is important communicate what is proposed well. This includes both shareables (presentations, videos and interactive demonstrators) and a clearly but accessibly documented design proposal that can be used by KLM for further development. The finalization phase is intended for these.

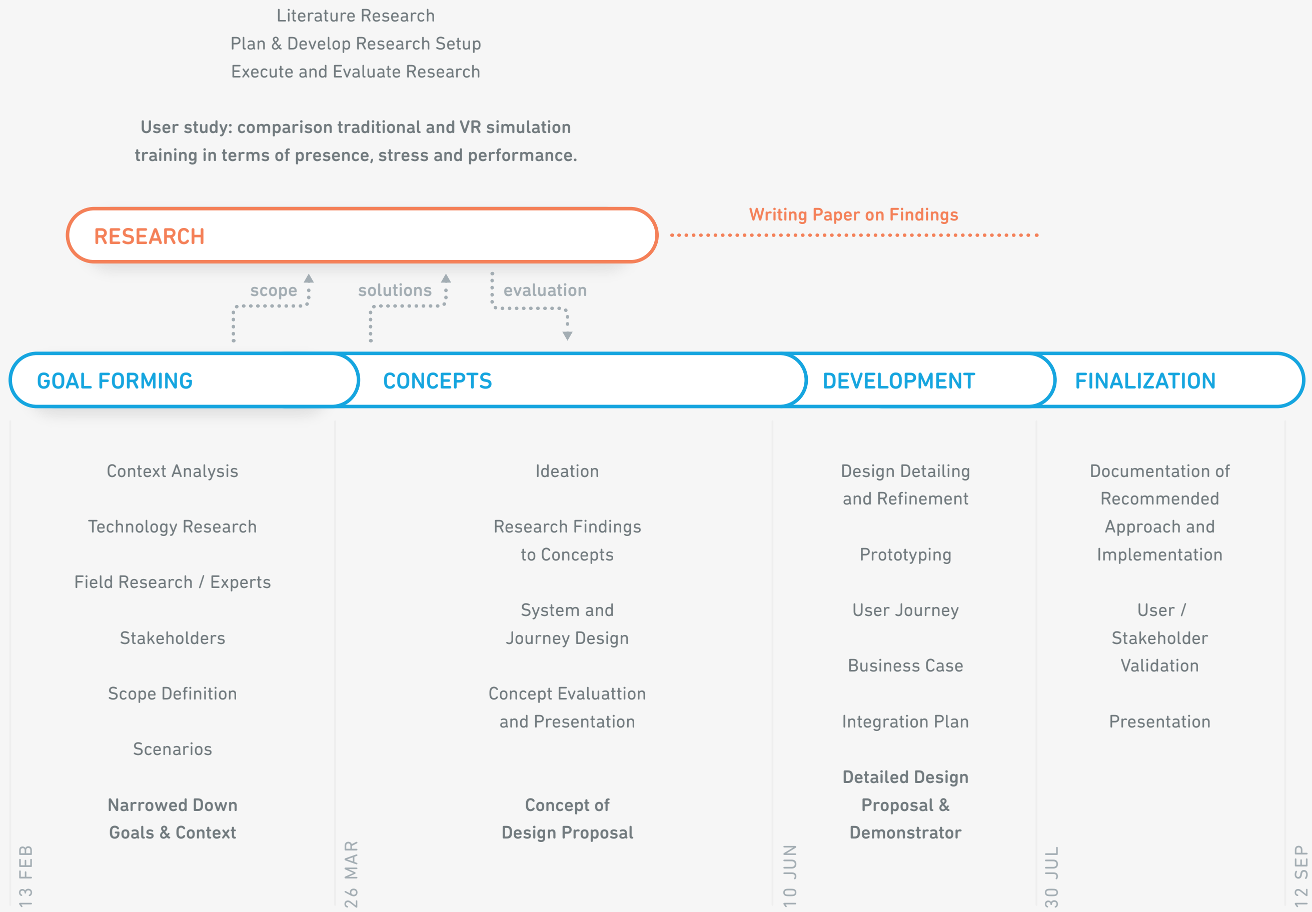


Fig.3 Global project planning

1 | CONTEXT

Fig.4 Boeing 747 Passenger Cabin (Smithsonian Institution, n.d.)

Crew Safety & Security Training

AT CSST A WIDE VARIETY OF METHODS AND FACILITIES ARE USED TO PROVIDE SEVERAL TRAINING PROGRAMMES. FURTHERMORE, IN THE RENOVATION TRAJECT, PLANS ARE MADE TO FACILITATE NEW WAYS OF TEACHING. THE DEPARTMENT IS DISCUSSED IN THIS CHAPTER.

Facilities

Current facilities

Besides some office space and meeting rooms for the staff, the current facilities offer conventional classrooms and several locations with simulation installations and gear.

Classrooms

A large portion of the training programmes takes place in a somewhat traditional classroom setting. The rooms are set up for an informal form of teaching, either targeted towards group work or a central discussion. Activities in the classrooms include:

- Discussions
- Storytelling / recounting personal experiences
- Lectures accompanied by audio-visual presentations
- Written examination
- Gamified / competitive exercises

Fig.5 Classroom before Crew Resource Management activity (Recurrent)

Fig.6 Using a door trainer during the Type Recurrent (FF)

Fig.7 Slide in use during CEET (Reker, 2016a)

Door trainers

Door trainers are used to train opening the (emergency) doors of the different aircraft types in different situations. These simulators have a set of options, such as a failure of the power assist and the display of the external surroundings (i.e. a monitor placed the window of the door with a picture or video of numerous conditions, such as fire). Besides the opening and closing of the door, the procedure for arming and disarming the slide is trained.

Cabin Simulator (CEET / CES)

A Cabin Emergency Evacuation Training (CEET) simulator is present, able to simulate heavy turbulence and a crash landing (including movement, smoke, sound and lighting effects). Furthermore it incorporates the arming and inflation of the emergency slide. The simulator is used to train procedures like those in normal circumstances, preparing for an emergency landing on either land or water and executing an emergency evacuation.

Rafts (post-evacuation)

Rafts are used to train and discuss survival gear and procedures in the case of an emergency landing on water. Due to the lack of water in the hall the training here is stationary and only includes a few exercises. At an externally located swimming pool, life-raft training is done on actual water.

Fig.8 Collaborative dealing with simulated toilet smoke development (initial training)

Fig.9 Fire in overhead compartment (initial training)

Cabin Role Play Scenarios (Unruly passengers)

A second, stationary aircraft cabin model is used to train scenarios for unruly passengers (from misbehaviour to hijacking attempts). For these simulations an actor is present to role play several scenarios. Simple self-defense and containment strategies are taught on an exercise mat.

Fire room

In the fire room fire related scenarios are simulated, including lithium battery fires, in cabin fire fighting and a disorientation exercise / evacuation. The simulation include limited use of representative props (a CO2 extinguisher (rather than Halon), gloves, protective breathing equipment (PBE)) and controlled fire and smoke at fixed places. In the simulations there is a clear trade-off between the degree to which fire can be simulated and the realism of the context, due to safety requirements. However, some of the simulations (e.g. the ones in initial training) include some more elaborate scenarios with elements of cooperation (see **Fig.9**)

Fig.10 Simulated CPR with AED during type recurrent.

CPR / AED

Reanimation is trained in a classroom (without tables), practiced on dedicated dummies with a training AED kit. The kit is representative of actual AED kits in every way, except for requiring to be mounted on metal connectors on the dummy. The (progression of) the patient's situation is basically always the same, while the kit guides the participants (in two available settings which are also present on the real kit) through several steps including mouth-to-mouth, compressions and administering a shock on the body. The simulation starts with the dummy already on a soft surface on the floor, with plenty available space and no bystanders.

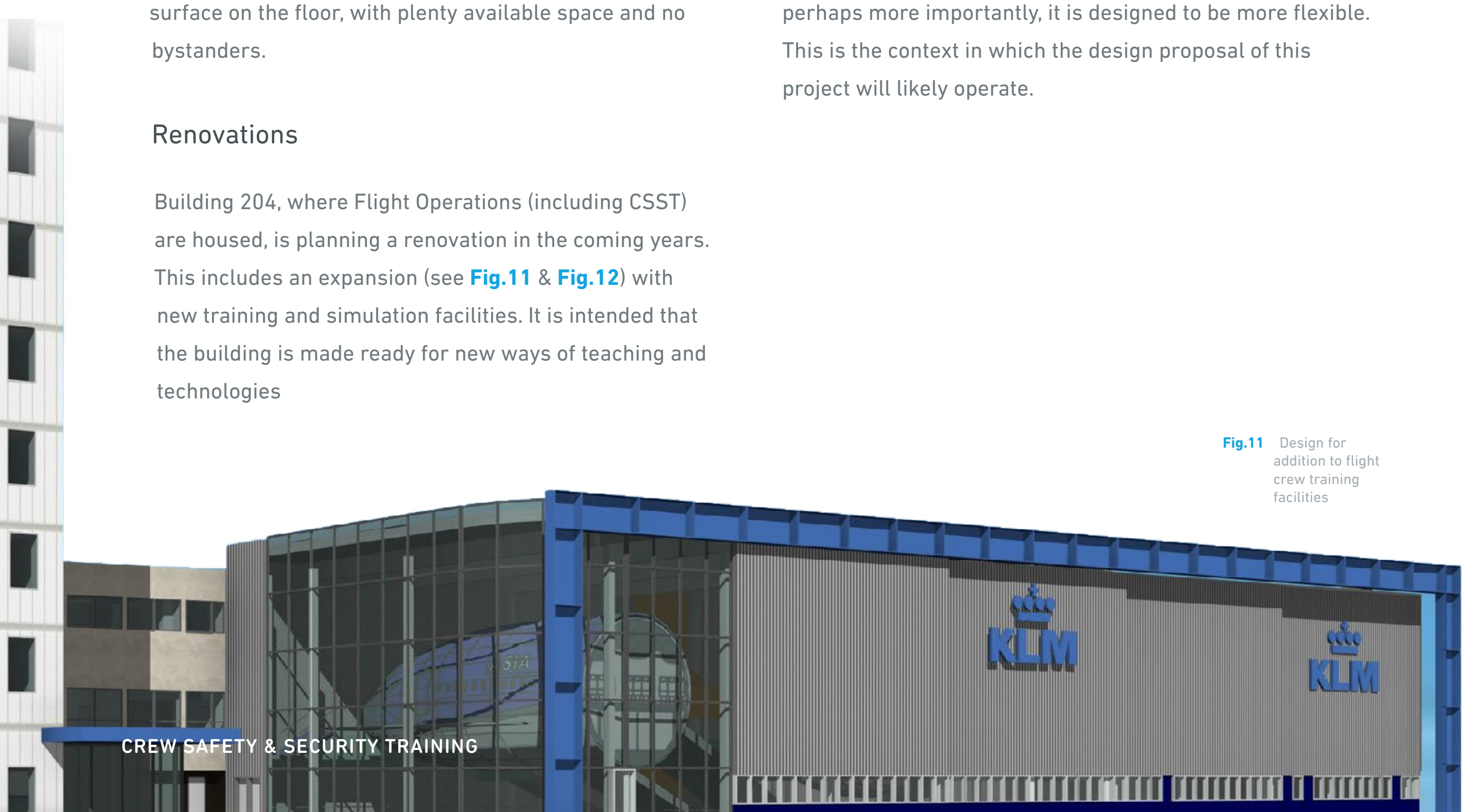
Renovations

Building 204, where Flight Operations (including CSST) are housed, is planning a renovation in the coming years. This includes an expansion (see **Fig.11** & **Fig.12**) with new training and simulation facilities. It is intended that the building is made ready for new ways of teaching and technologies like VR and AR. CSST management lists as primary motivators:

- Less dependency on simulator suppliers
- Increased customization and control of the training methods
- Improved insight and awareness amongst the crew as a result of the teaching.

In the current proposal there is space dedicated to VR and, perhaps more importantly, it is designed to be more flexible. This is the context in which the design proposal of this project will likely operate.

Fig.11 Design for addition to flight crew training facilities



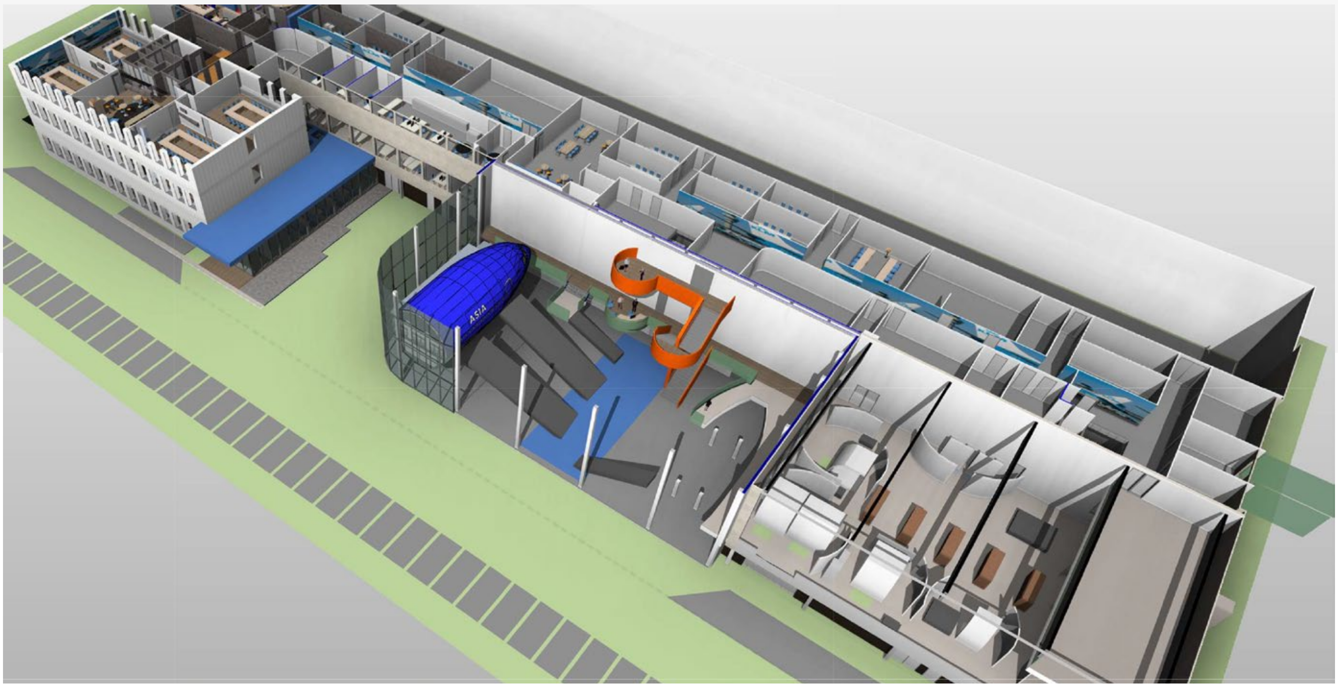


Fig.12 Interior of facilities after renovation and expansion in current mockups

Training Programmes

CSST offers several training programmes to cabin personnel: primarily initial (when starting at the KLM cabin crew) and recurrent training (2-3 days per year), and on specific occasions conversion (when flying a new aircraft type) and refresher training (after period of absence). Furthermore, the training programmes include certain training modules part of multiple programmes, such as Crew Resource Management. KLM's Training Operations Manual (TOM) acts as a syllabus for these programmes, while the CSST department determines in part how the topics are taught.

Recurrent Training

There are three recurrent training days, named RF (type recurrent), FF (general recurrent) and RQ (3-yearly recurrent) (see **Fig.14**). These are mandatory for all KLM cabin crew.

Content

The FF covers safety and security procedures for all aircraft types, both theoretically and in practice (using simulation). Its contents and methods are changed each year. Unique topics to this recurrent are normal procedures (safety checks, briefings) and an elaborate emergency landing / evacuation simulation. It also includes some firefighting exercises.

The RF has a slight focus on specific aircraft types, and includes examination and door training specifically for those. It also incorporates CPR training and crew resource management (use and knowledge of safety and security related equipment). There is little to no overlap with the FF.

The RQ training includes raft training and the use of pyrotechnics (extinguishing actual fire), and includes elaborate training (large portion of afternoon) on unruly passengers. Other than that, there is some overlap with the RF and FF training days. However, the RQ mixes cabin crew and flight (cockpit) crew.

Experience

All three training days were observed and participated in. Observations on the participants are noted in the stakeholder analysis, but the following are some general findings on these programmes:

- The days are crammed with activities, making it hard to go really in depth
- Many simulations last less than a minute, excluding CPR and CEET
- Much of the theory is covered in a gamified manner (competitions, game formats, fun)
- Simulations focus more on technical realism than perceived realism

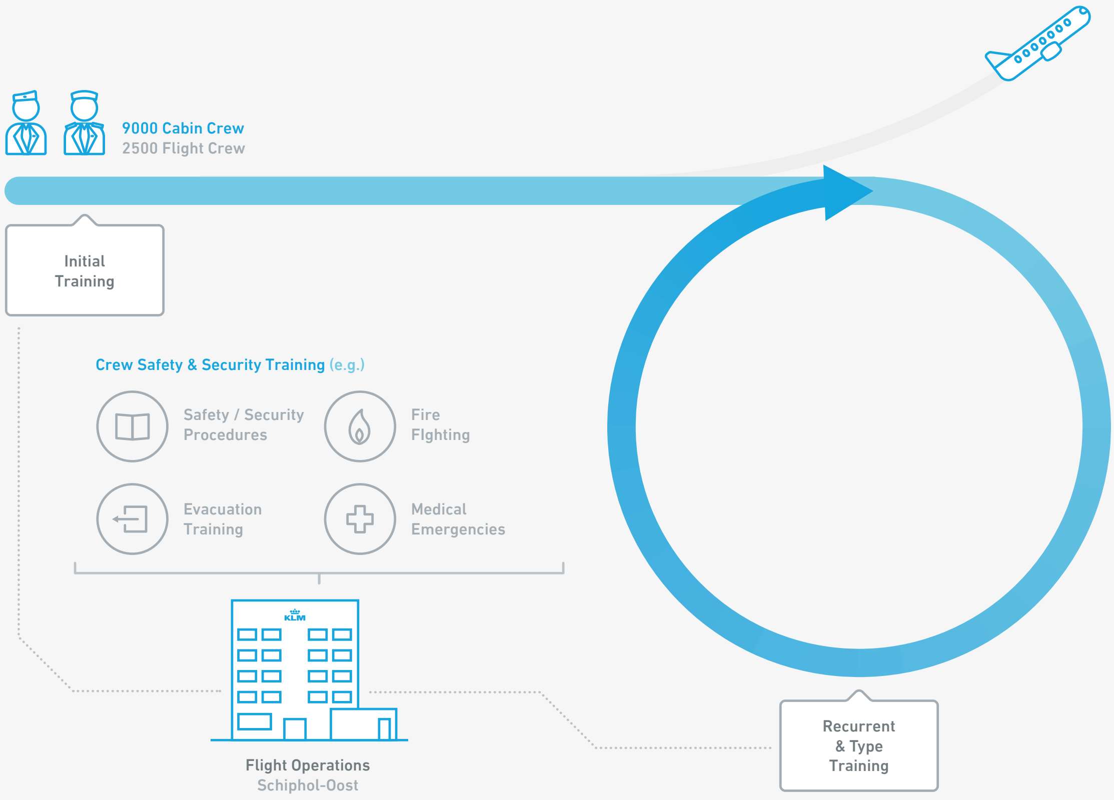


Fig.13 Core training programmes and context overview

- There is little evaluation of the participants' performance.
- Much of the training is collaborative or of a social nature.

Initial Training

The initial training (or base training) is a 4 week training (excluding preparations) for all new cabin crew at KLM (except those transferring from KLM Cityhopper) and covers all general topics and examination on those. It is followed by conversion training for the aircraft types the participant will be flying, including familiarization flights.

Content

Compared to the the recurrent programmes, things are covered in more detail, with more frequent evaluation and examination. Furthermore there is much more time to go into depth. While in general the topics covered are similar to those of the recurrents, some exercises are unique to .the initials and some unique to the recurrents. For instance, water survival training in a swimming pool is covered solely in the initial training, while a disorientation exercise with obstacles is unique to RQ.

Experience

One training day, primarily covering fire fighting and rejected takeoff (RTO) scenarios, was observed and participated in. About half of the group comprised transfers from different airlines, the other half were starting CAs. The following are some general observations on the programme and teaching style:

- Fewer topics are covered than during recurrents, so the teaching is more detailed.
- The learnings are often primary knowledge, rather the small refinements that were the primary learnings during the recurrents.

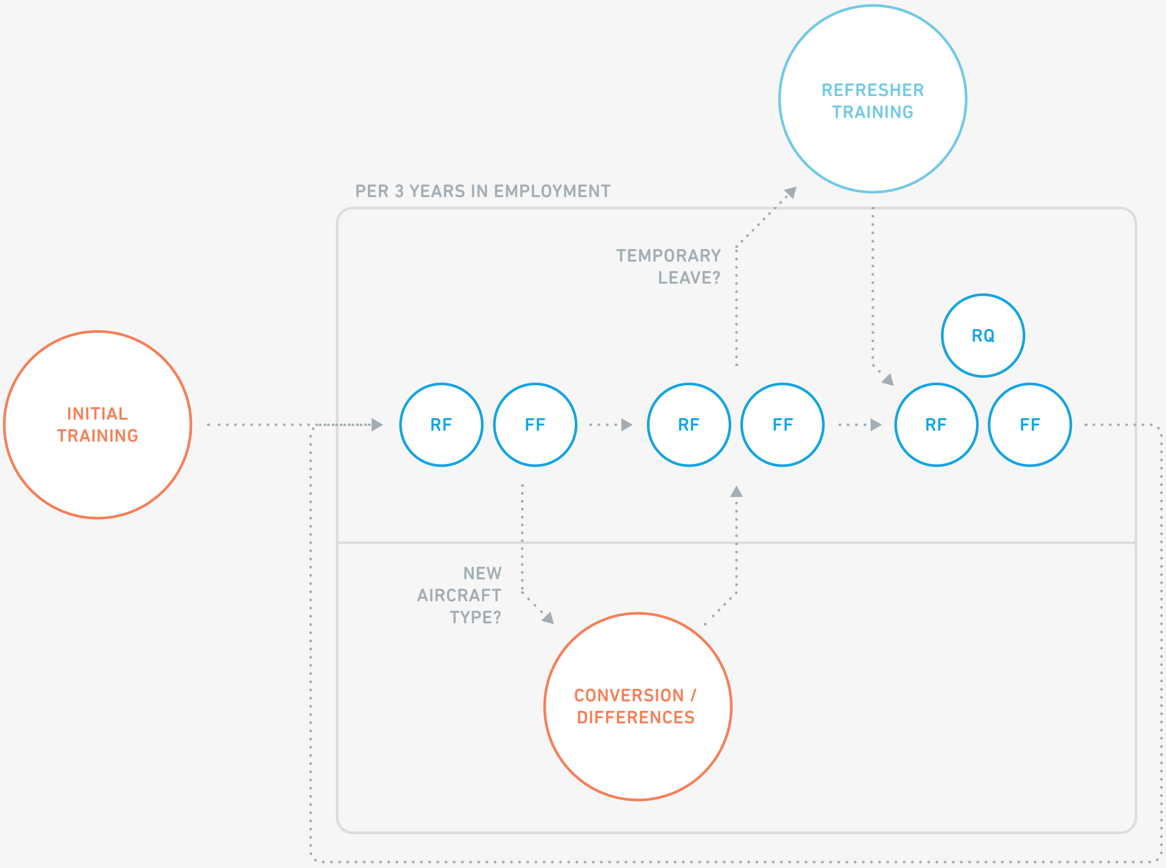


Fig.14 Detailed overview of training programmes

- Theory is covered in a relatively traditional manner (examinations, homework) compared to the recurrents.
- Practical training is often like a tutorial (trainer instructs the actions) or frequently interrupted (trainer gives granular feedback). The focus seems to imprint the procedures.
- Group is social, chatty and easily distracted, and their lack of experience slows down the pace of the training.

Stakeholder Analysis

DIFFERENT PARTIES HAVE A STAKE IN THE OUTCOME OF THIS PROJECT, WITH DIFFERENT NEEDS AND MEASUREMENTS OF VALUE. THIS CHAPTER WILL IDENTIFY THEM, AND DESCRIBE THEIR IMPLICATIONS ON THE PROJECT.

Fig.15 displays them, their likely proximity to the final design and their main interests in relation to that design.

KLM Crew

The thousands of members of the KLM on-board crew (9000 cabin, 2700 cockpit (KLM, 2016c)) have to undergo safety & security training programmes as part of their base training and as periodically recurring training in order to be allowed to fly.

From observing the recurrent training programmes and talking to both participants and trainers, it seems that the majority dislike having to do the training. The general sentiment is that they already possess all required knowledge and skills, and are mainly there because it is mandatory. A few measures have been taken to keep the attention of the participants while increasing enjoyment and general usefulness:

- Lot of room for socializing, collaboration and discussion (personal stories and experiences)
- Gamification of virtually all theoretical matter (competition and play)

Fig.15 Main stakeholders and their interests

Characteristics

As the trainees are the core target group for this project, with the most proximate interaction with the intervention that is to be designed, it is worthwhile to consider their characteristics.

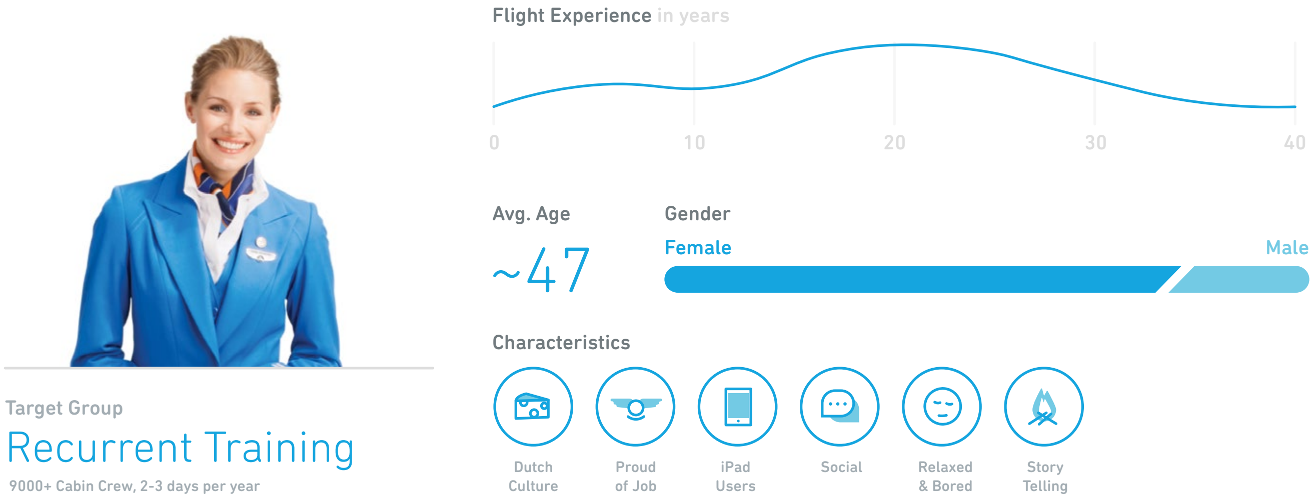


Fig.16 Generalized characteristics of recurrent training participant

Recurrent training participants

KLM's cabin crew has aged somewhat in recent years, resulting in an average age of 47 amongst the participants of the recurrent training programmes. Furthermore, most are female and have decades of experience. The 9000 cabin crew have two yearly training days, and one additional training every three years. By observing them during the training and talking to some of them, the following characteristics seem to be common:

- **Dutch culture:** openness and directness are strongly present in the corporation and among its personnel
- **Proud of job:** Most have a strong conviction to be dependable and deliver good service
- **iPad users:** KLM personnel is supplied with iPads, which are also used during training. This seems to be the type of technology they are very comfortable with.
- **Social:** Large portions of the training are spent socializing and discussing the topics, even though most participants don't know each other.
- **Relaxed & bored:** while the participants don't really enjoy having to do the training, they are laid-back and relaxed throughout.
- **Storytelling:** Participants like to share their personal experiences and discuss them with the group and trainer.

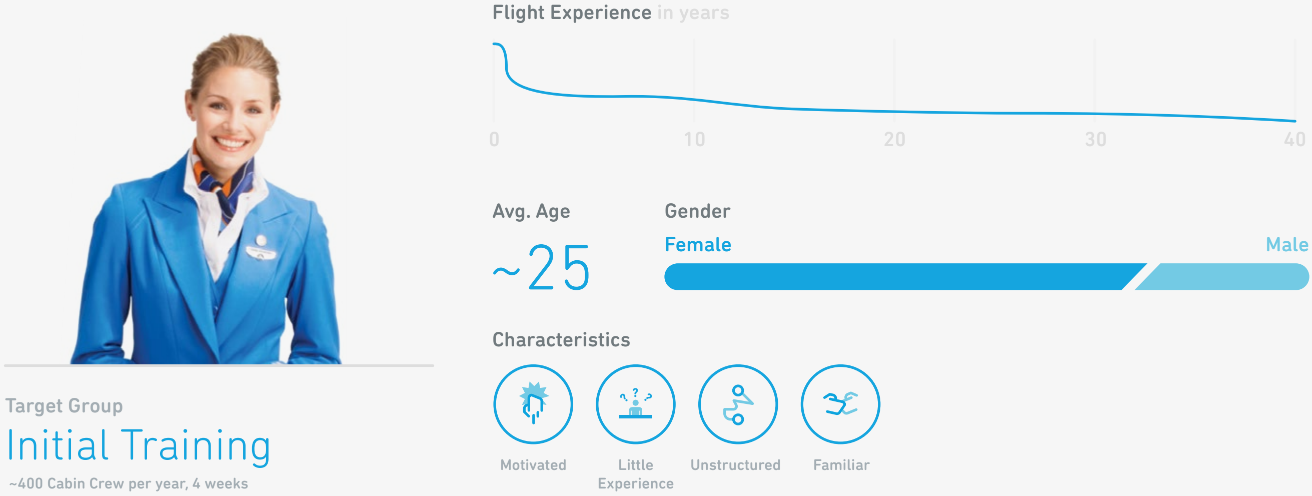


Fig.17 Generalized characteristics of initial training participants

Initial training participants

Yearly, several hundreds of new members of the KLM cabin and cockpit crew (around 400 in 2016) undergo a base training that takes four weeks (20 days). This new personnel either doesn't have any experience, or is transferring from another airline.

- **Motivated & curious:** Relative to the recurrent participants, this group is largely new to the profession and eager to perform and learn.
- **Inexperienced:** Members of this group may lack familiarity with KLM's corporate culture and way of working and / or have little to no professional flight experience. This makes them potentially unaware of the recommended procedures, prone to make mistakes and unfamiliar with what a real-life safety / security situation feels like.
- **Unstructured:** Related to the lack of experience, the execution of procedures and collaboration go less smoothly. Training procedures are often interrupted.
- **Familiar:** The participants are social, but in a more familiar way than the recurrent training participants, as they are in the same classes for four weeks.

Needs

The flight crew wants a solution that:

- **Is accessible and easy to use:** acceptation of the design, especially when it introduces new technologies and ways of interaction, is paramount. Flight crew needs to understand how it works intuitively, and focus on the training itself.
- **Makes training dynamic and exciting:** participants are most eager to participate when the training is exciting, fun or competitive.
- **Gives a sense of better preparation:** The crew should be confident that the training has sufficiently prepared them for real-life emergency scenarios, and accept it as representative of the real thing.

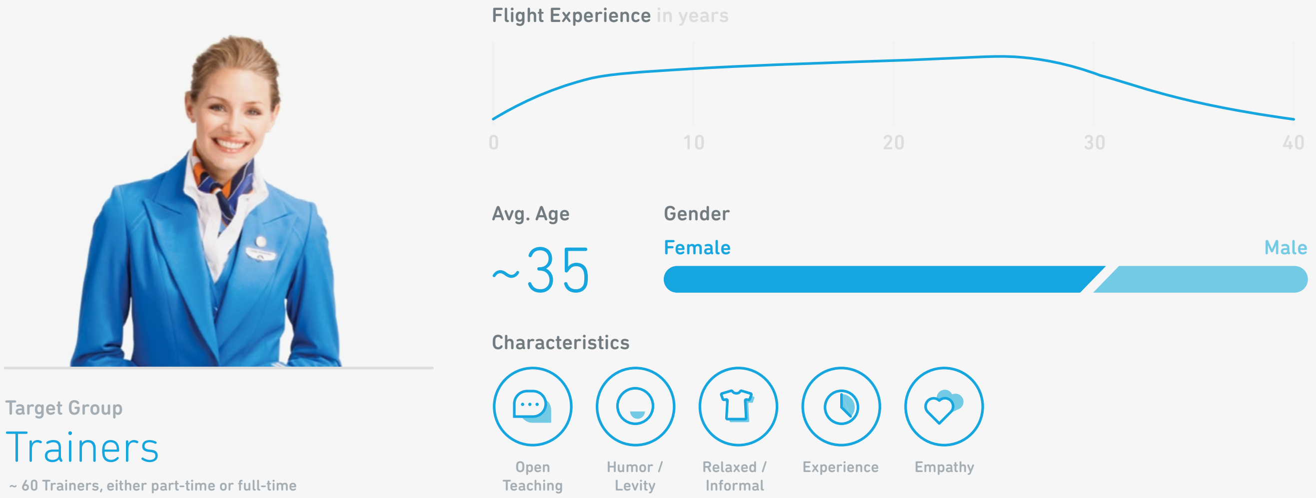


Fig.18 Generalized characteristics of CSST trainers

Safety Security Trainers

The Safety & Security Training department at KLM has around 50 employees, most of whom are teaching either part-time or full-time. After the participants of the training programmes, they have the most proximate interaction with the design that is to be created. While each teacher has her / his own style of teaching, they have some characteristics and goals in common. Four teachers were interviewed (see appendix A) about their teaching goals, what they would like to see improved and what potential they saw in immersive, virtual simulations. In addition, they were asked about their teaching style.

Characteristics

Learning goals

The trainers cite diverse goals in their teaching, including:

- Aim to make the procedures so clear that you can rely on them in case of emergency.
- Incorporate a positive and serious attitude towards safety and security
- Increase awareness and the understanding of the need for high safety standards, and explain the reasoning behind them

They think the following learning goals are hard to achieve or incorporate in the programme:

- Providing background information that creates understanding
- Creating behavioural change within a single day

They are open to VR / MR technologies, and think it can be use for the following purposes:

- Convincingly and tangibly putting you in any possible context
- Allowing people to make mistakes and see the consequences
- Communicating very specific scenarios, and increase overall understanding

Teaching style

The trainers self-describe as:

- Relaxed
- Humorous
- Empathetic and open for interaction
- Informal

They all find it important to customize some aspects of the activities according to their teaching style. Some have mixed feelings about the gamification of the programme. Many think it is engaging to the very practical target group. Others see it as a distraction from the content. Furthermore, some trainers put more emphasis on teaching procedure, while others focus on professional judgment.

Evaluation

Evaluations often concern a conflict between judgment and procedure. On the one hand the trainers think making considered actions that deviate from the FSSM are not necessarily mistakes, and often a valuable ability. On the other hand some of the participants are quite forgetful of the official procedures. According to the trainers, participants often leave out aspects of the procedure, specifically because they know it is fake.

In the evaluations, general points of improvement of the group are highlighted. Feedback is delivered in a positive manner, and hardly ever towards a specific person. This is in line with KLM's 'just' corporate culture. While participants are instructed to give each other feedback throughout some exercises, one trainer stated that they are often unwilling to express their critique. Furthermore, many exercises are so simple there is very little to give feedback on.

Needs

Safety / Security Trainers would benefit from a solution that:

- **Makes communication clear:** from a pedagogical perspective, the solution should make communicating the learnings easy and fit with the social and collaborative style of teaching. It should increase understanding into the background or reasoning of procedures.
- **Makes training adaptive:** a big potential of virtual simulations is the almost limitless control over the variables. This makes it much more feasible to create tailored exercises to serve more specific learning goals, and fit the teacher's personal style of teaching.
- **Evaluates performance:** there is no strict way to track how people perform in simulations. A better way of monitoring and recording this, could improve the quality of the evaluation and examination. However, this should not make the participants feel policed.

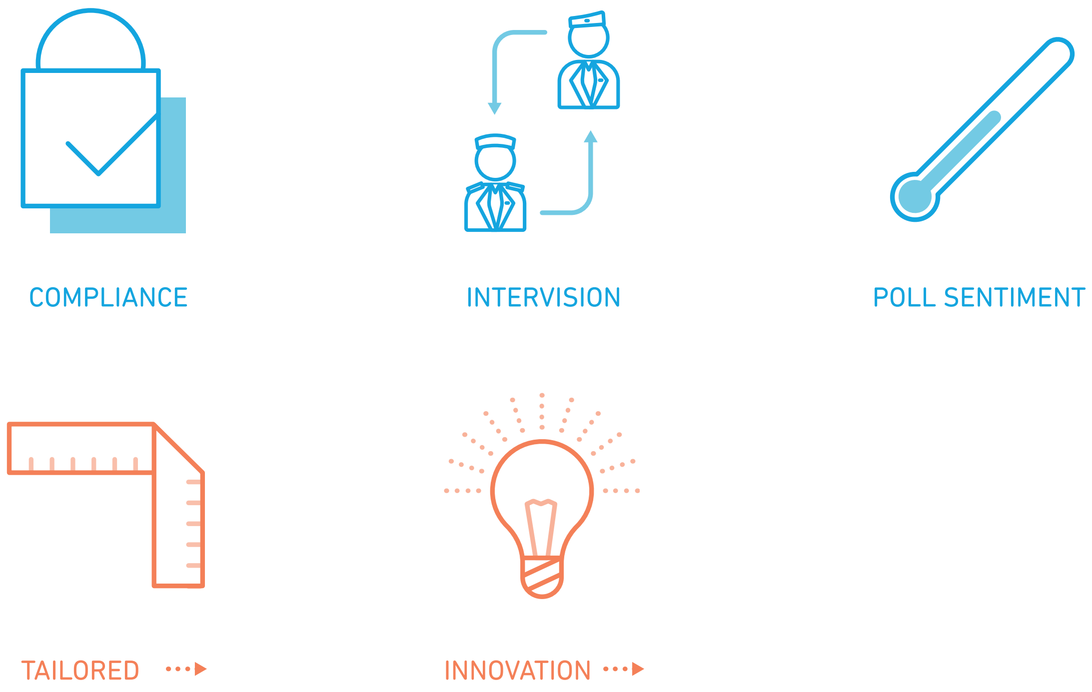


Fig.19 Learning and development goals of CSST, according to CSST Manager Roel van Leeuwen

Safety & Security Training Management

To identify what the management of the Safety & Security Training department hopes to gain from this project, the topic was discussed with several people that take on managerial roles at the department. Because the department is relatively small, the people in management are still quite closely involved with both the teaching programmes and the trainers.

Characteristics

Every year the departments rethinks part of the training programmes. This is in part done to comply to new regulation, in part to teach the participants a wider range of content and keep the recurrent training somewhat interesting for them. According to Roel van Leeuwen, Manager at CSST, the aims of the department are as follows (see **Fig.19**):

- **Compliance:** The training should comply to the KLM safety standards and all regulation, as described in TOM, but remain interesting and engaging.
- **Intervision:** The department has a strategy to make teaching facilitating, rather than solely instructing. Therefore, the aim is to allow participants to learn from each other and share experiences
- **Poll sentiment:** The training days provide a good opportunity to poll the sentiment of the crew, and evaluate what issues they run into in their daily work flow

Two areas that are spear point for further development are:

- **Tailor-made education:** CSST wants to give participants more personal and specific training. The department sees e-learning as the primary strategy to achieve this.
- **Innovation:** The department strives to be continuously improving the quality and efficacy of their training. It seeks out a diverse set of strategies, including a lot of gamification.

According to Ard Rombout (compliance expert and manager at CSST), CSST is best aware of what is important to cover in training. For instance, they have pushed safest course of action / improvisation training activities that are not defined in the regulation. As such compliance, while necessary, is not always the most important thing to focus on.

Needs

The management of the training department wants a solution that:

- **Prepares the crew better:** High quality training is ultimately the primary goal of the department. The crew should be well prepared throughout the year, and be confident in their abilities.
- **Makes simulations more versatile and scaleable:** With the ever changing training programmes, adaptable solutions are key.
- **Makes the performance evaluation realistic:** Having performance data of true to life simulation experiences increases the evidence of adequate preparation for real-life emergencies.

KLM Management

In the original request from KLM that lead to this project, a secondary goal was to contribute to a platform for the use of technologies like VR and MR in the company. To further explore this desire for a display of technological pioneering, Guido Helmerhorst, former Social, Business & Technology Architect and current Innovation Manager (Corporate Innovation Department) at KLM, was interviewed (see Appendix B). He has been involved in serious gaming and VR projects at KLM.

Regarding safety, KLM is interested in maintaining and strengthening their safety standards. They have been named the safest European airline on multiple occasions, including in 2017 (JACDEC, 2017).

Characteristics

According to Helmerhorst, technological innovations can be initiated from anywhere in KLM, and often come from suppliers, academia, startups or competitors. The innovations start in the shape of experiments, but in order to be implemented they have to go through many levels in the company hierarchy. For further development, KLM management typically requires projects to be:

- **Undisruptive:** KLM relies on stability in its operation, and is risk and mistake averse
- **Easily Implemented:** Similarly, the solutions should integrate with how things currently work
- **Good Business:** The project should have a good business case. While this is mostly measured in projected financials, it can also be compliance to the missions statements and OGSM policies of the company and its divisions.

Helmerhorst sees the strongest business case for immersive technologies in the company in regard to planning and coordination: reducing the time spend allocation resources and figuring out logistics. In the case of training this could be increasing the flexibility, availability and scalability of simulation exercises. In the case of maintenance this could be AR remote assistance.

Due to its size and deep organizational structure, at KLM innovation is typically a bit slow. Helmerhorst predicts in 5 years most departments will have completed VR experiments, and it will take at least 10 years before the business has fundamentally adapted. He suspects AR will take longer, as it would require deep integration in the context, where VR is typically more isolated. KLM wants to be known as the most innovative airline of Europe, but Helmerhorst states the company hasn't figured out how to communicate that.

Needs

- **Better, Cheaper Training:** Ideally, the business case would reduce time and money spent on the planning and allocation of resources.
- **Safety Standards:** KLM wants to stay at the forefront of flight safety, both in training and in practice.
- **Integrated Solution:** The design should not completely disrupt the current ways of working, but easily and seamlessly integrate in its context. Involved risk should be minimized.
- **Innovation Brand:** The resulting design should promote innovation and the use of immersive technologies between the company's divisions.

Aviation Regulation

Aviation organizations and government branches provide legislation, regulation and procedural guidelines for flight safety, security and the training thereof. Ard Rombout, manager at CSST with expertise in regulation compliance, was interviewed on this topic. On a global level, the International Air Transport Association (IATA) provides a guide on best practices (International Air Transport Association, 2017) and an agreement upon safety standards (IATA Operational Safety Audit (IOSA)). For European and US air travel, additional requirements are posed (e.g. from the European Aviation Safety Agency (EASA))). Then KLM is subject to Dutch legislation. On top of that, KLM sets its own safety standards (KLM Basic Operating Policies). The requirements for the training programmes in KLM are formulated internally in the Training Operations Manual (TOM), including those at CSST. TOM does not always fully specify how things should be thought, but the format of the training designed at CSST is subject to approval of the Inspectie Leefomgeving en Transport (ILT).

Furthermore, all regulatory parties perform announced and unannounced inspections. Within the scope of this project it is perhaps unlikely that a solution is designed that can be immediately approved by all regulatory parties, it is important to take into account how they will influence long term implementation.

Characteristics

- **Many layers and parties:** Basically all sources of regulation and procedure, one a superset of the other, have a say in what complies to the set standards, and check whether training facilities match that level.

- **Exceptions can be made:** It is possible to convince these parties to make exceptions to written rules. A representative gets to inspect and experience the proposed alternative solution. If the quality of the alternative is adequate, these representatives have the power to allow an exception.

- **Control teaching, not evaluation of performance:** Even though there is a set list of requirements on what should be taught, it is seen as the airlines own responsibility to ensure that all trained crew performs at an adequate level. As such, regulatory parties don't set any requirements on how well people should perform during training. The examinations during training are created internally at KLM.

Needs

- **Better safety standards and training:** Parties involved with guidelines and regulation are stakeholders in the overall performance of cabin attendants. While they don't set requirements for how well CAs should perform, improved learning may convince them the accept the proposed solutions.

- **Demonstrable validity of simulation:** Proof that the proposed simulation is fulfills relevant requirements that set in TOM, or forms a convincing alternative, must be given before introduction.

Conclusion

While there are many stakeholders with differing needs, on first glance there seems to be little conflict between those needs. Small potential conflicts of interest include:

- The participants want to be able to make mistakes and learn from them, but CSST trainers and management want to evaluate the personnel's performance. Increased monitoring might make participants feel like they are being examinated continuously.

- There is often a trade-off between training quality, cost and time. Different parties would balance these differently.

Company & Competitors

THIS CHAPTER WILL GO BRIEFLY INTO KLM AS A COMPANY, ITS DIGITALIZATION EFFORT AND VENTURES INTO TECHNOLOGIES LIKE VR. ADDITIONALLY, A LOOK IS TAKEN WHAT COMPETITORS AND COMPANIES WITH A SIMILAR CONTEXT ARE DOING IN TERMS OF INNOVATION.

KLM facts and figures

KLM is a Dutch airline, part of AIR FRANCE KLM (since 2014), for both passenger and cargo air transport. The company was founded in 1919 (KLM, 2016a), and is owner of subsidiaries Transavia, KLM Cityhopper and Martinair. The company employs around 32000 people (KLM, 2016b), of which more than 9000 cabin crew and more than 2500 flight crew (KLM, 2016c). AIR FRANCE KLM transports more than 77 million passengers per year.

Mission

KLM wants to deliver reliable service to its customers in a pragmatic way, safely, efficiently, service-oriented and sustainably (KLM, 2016b). They hope to continuously grow in their vast international network, with Schiphol airport as their base.

Vision

KLM has the following vision for the company as part of Air France KLM:

> “*KLM wants to become the most customer centric, innovative and efficient European network carrier. By merging with Air France KLM has come to occupy a leading position in the international airline industry. KLM wants to be the customers' first choice, to be an attractive employer for its staff and, a company that grows profitably for its shareholders.*”
>
> (KLM, 2016b)

Fig.20 KLM's first direct scheduled line between Amsterdam and New York in 1946

Corporate culture

KLM has a self-described culture of 'Dutch pragmatism'. Regarding safety they apply the Integrated Safety Management System (ISMS) (KLM, 2015a) and a so-called 'Just Culture' (KLM, 2015b). The latter means that employees are not punished for mistakes which are to be expected given the training they have had, but that it is encouraged to report upon these mistakes. This model is different from other airlines, some of which tolerate almost everything, while some others have repercussions for every mistake. ISMS is KLM's vision and policy on safety. In general, it encourages the reporting of unsafe situations, evaluation of incidents, compliance to rules and individual contributions to safety. There are five core safety principles:

- Work safely
- Comply to the rules
- Report unsafe situations
- Help each other, and check upon each other
- Make sure you are fit to work

Digitalization and immersive technologies at KLM

While KLM, being a large company, is somewhat slow in completely adapting technological change, continuous efforts are made and experiments are done to digitalize the company's work flows. The company has dedicated offices for innovation and digital transformation, which collaborate with different departments and external parties.

iPads for everyone

Over the past years, KLM has supplied cockpit crew and pursers (KLM, 2013), and at a later point the remainder of the cabin crew and front line personnel (Hundepool, 2016) with iPads. They are used to provide more personal treatment of passengers, make flight manuals searchable and significantly smaller and form a portal for information and communication. At CSST, iPads are utilized to practice theoretical knowledge.

VR evacuation training

At Hangar 14 of Engineering & Maintenance, a mobile VR training for evacuation procedures was recently developed (see **Fig.21**). The user views 360 degree videos shot in the hangar, and makes choices throughout the evacuation scenario by gazing in the correct direction. The videos feature

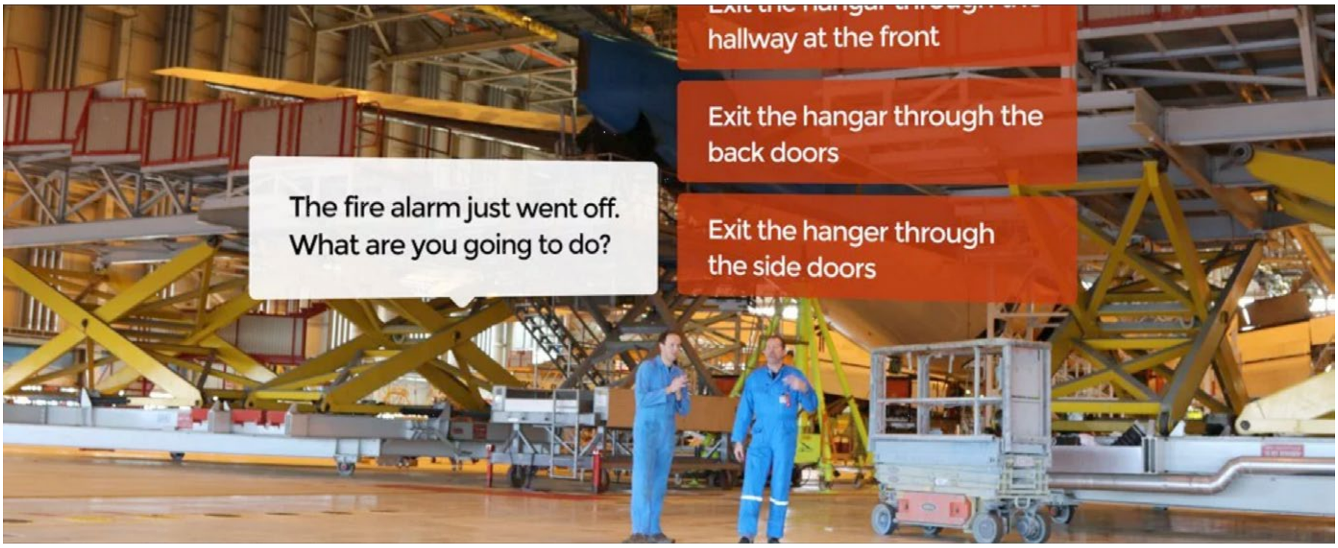


Fig.21 VR evacuation training of Hangar 14 (HSI Events, n.d.)

smoke and sound effects, and the user experiences the consequences of poor decisions (e.g. getting stuck in a smoke filled elevator). While the degree of freedom is relatively low, the scenarios present interesting challenges and stress factors. The yearly cost savings versus evacuating the actual hangar are estimated between 50 and 75 thousand euro (Helmerhorst, 2017).

Virtual Aircraft Visit

Recently the Virtual Aircraft Visit, a virtual tour of KLM's aircraft types comprising 360 degree photographs and some points of interaction, was approved by ILT as a replacement for the mandatory visitation of aircraft types on the ground and familiarization flights after conversion training (except the conversions part of initial training). The solution was developed at CSST to familiarize crew with the layout of different aircraft types, and results in a significant saving of time and money.

Mixed Reality E&M Training

At the training department of Engineering & Maintenance experiments are done with the use of mixed reality (using the Microsoft Hololens) as a way to make engineers understand structure of the systems of an aircraft better. 3D projections of the (normally invisible) air conditioning systems, spatially positioned, interactive and animated, would serve as a replacement for the 2D technical drawings in the current lesson plan. Henny van Kessel, education consultant on the project, was interviewed (appendix B). According to her, it would likely speed up lessons, improve collaboration during training and increase learning and understanding. She prefers the application of mixed reality over virtual reality, as she beliefs it enables a more social way of learning.

Competition & Innovation in comparable contexts

While the aviation industry is quite slow to adopt new technologies, there are some examples of airlines and related companies using immersive technologies in the training of their personnel. Furthermore, there are initiatives in comparable contexts of emergency, safety and security training where these technologies are utilized.

VR aircraft inspection training for IATA (Brightwave Group, 2015)

A VR demo for the training for inspection and layout of aircrafts was developed for IATA. It goes over the full routines, with some interaction and positional head tracking (no full freedom of movement). It was found that this made trainees learn more quickly versus a conventional classroom training. However, the speculated value is mostly in the ability to simulate a wide variety of scenarios and simulations.

Re-Lion Blacksuit / Redsuit

Re-Lion is a Dutch company that creates high tech VR simulations for (militaristic) defense, security (Blacksuit, see **Fig.24**) and firefighting (Redsuit) training. Their training

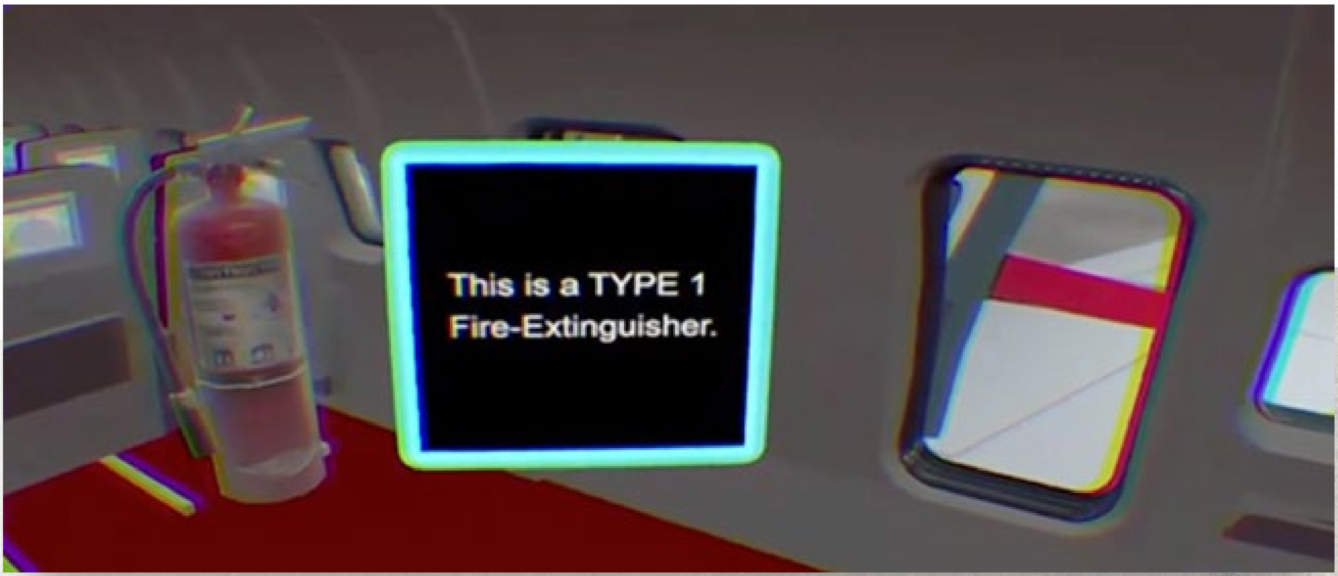


Fig.22 IATA Aircraft Inspection demo in VR (Brightwave Group, 2015)

involves full-scale collaborative operations with free movement and full-body motion capture. The company was visited to investigate how challenges were faced for such a large-scale system (see Appendix B).

The company builds both the hardware and software solutions completely custom, with parts of the system replicable between clients and projects. They give trainers who control the tool a lot of freedom to customize simulation whilst retaining user friendly interfaces.

The setup is completely portable and scalable as it relies largely on radio communication between a central Exercise Control system and the body suits with integrated computer (backpack), sensor system, physical props and head mounted display. Furthermore, a 'Spectator Station' is present to replay, observe and evaluate simulations afterwards in 3D environment.

It was found that the system provides soldiers with a better training in terms of dealing with unpredictable, stressful situations, both mentally and tactically, but lessened the physical ability compared to live training. However, the system is more versatile and significantly more affordable than traditional training, despite the level of custom development for a niche market.

Fig.23 MR projection of cockpit with overlay (JAL, 2016)

AR Training Flight Crew & Mechanics at Japan Airlines

Japan Airlines has developed several training modules with the Microsoft Hololens (Choney, 2016) to replace paper based training (see **Fig.23**) with something more graspable and interactive. Despite using a mixed reality device, the application does not integrate with existing space and objects, and can thus almost be seen as VR.

Fig.24 Re-Lion Blacksuit (Re-Lion, n.d.)

2 | SIMULATIONS

Simulation Training

> A SIMULATION IS AN ISOLATED REPRESENTATION OF HOW A REAL-WORLD SYSTEM OR PROCESS BEHAVES OVER TIME.

In the context of this project, it refers primarily to interactive simulations involving one or multiple human actors, where the performance of these humans is what is being observed and evaluated.

Goals of simulation

Simulation based training has proven to be an effective didactic tool in various industries (Alinier et al., 2006, Freeman et al., 2001, Chittaro, 2012). While not the entire training programme at CSST comprises simulations, their application is necessary to serve several goals:

Experience and practice safely

Training simulations, like all simulations, have the benefit of being largely isolated from the external world. They are environments in which critical situations and emergencies can be experienced and acted upon safely (potential safety risks from simulator use excluded). This gives users preparatory experience and an understanding how cause and effect relate.

Evaluate real-world performance

If a simulation is a sufficiently realistic representation, the performance of training participants is a good indicator of their real-world performance. It thus serves as individual proof of competence or lack thereof.

Immersive and rich learning experience

Interactive simulations give training participants the opportunity to practice their behaviour in a scenario without explicit guidance. This makes it yield more practical experience than pure theoretical input, and serves as a closer approximation of both real-world context and performance than tutorial based training. Freeman et al. (2001) 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".

Limitations and challenges

Abstraction

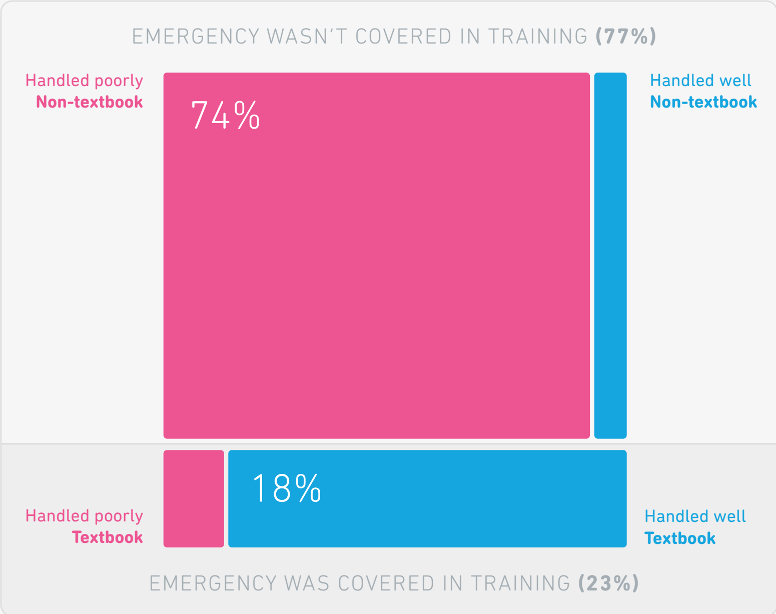
Every simulation, especially those of critical situations, has a degree of abstraction from reality: not every factor can realistically be incorporated and not all possible courses of action (e.g. ones with high risks) can be allowed to happen. However, a lower fidelity simulation doesn't necessarily decrease the validity of its representation of real-world performance (Dahlstrom et al., 2009).

Human involvement and attitude

It is likely that awareness that the situation you are partaking in is a simulation influences decision making in that situation, because it means that experienced threat of the situation is not real, and that your actions don't have the repercussions they would if it were. For instance, there is very little reason to panic during an announced fire drill. However, depending on the execution, a simulation may be able to cause a suspension of disbelief in its user (Muckler, 2017), based both on the fidelity of the simulation and the user's susceptibility (emotionally, sensorially and cognitively) to what is being simulated.

Variety of simulated scenarios

Most simulators can only simulate a small set of predefined scenarios, leading to a training programme filled with 'textbook' scenarios. While this results in good performance for those scenarios, this may not adequately prepare for the real world. For instance, Burian et al. (2005) found that the majority of critical situations in aviation (around 80% in their sample (n=107)) are non-textbook situations, coinciding with dramatically worse performance of flight crew (see **Fig.25**).



> *Training is effective at ensuring good performance in textbook emergency scenarios, but in reality most emergencies aren't textbook.*

Fig.25 Flight crew (pilot) performance and textbook coverage for 107 reported incidents in Aviation Safety Reporting System (Burian et al., 2005)

Stress in simulations

Stress, in this case defined as "a process by which certain work demands evoke an appraisal process in which perceived demands exceed resources and result in undesirable physiological, emotional, cognitive and social changes" (Kowalski-Trakofler et al., 2003), is a significant factor in human performance in critical situations. While no absolute relationship between stress and performance has been established, multiple of its effects are likely to be of influence:

Arousal vs. performance

The Yerkes-Dodson Law (Yerkes & Dodson, 1908), shows an empirically established relation between arousal (result of stress) and task performance, for which there is an optimum (see **Fig.26**). This means that very high stress can potentially impair performance, but so can a lack of stress (e.g. a low-stakes training scenario). However, a level of stress has been shown to increase learning performance, while repeated exposure to stressful situations normalizes the effects (Bong et al., 2010).

Tunneling

Stress also typically causes tunneling, an effect where one stops evaluating multiple courses of action and starts disregarding environmental cues in favour of a single focus (Burian et al., 2005). Additionally, the ability to process information is reduced. Stress has for instance been shown to reduce performance in following checklists procedures among medical residents (Harvey et al., 2012). These things don't necessarily mean that task performance will go down under stress, but clearly they are influential on the decision making process.

Communication under stress

According to Kowalski-Trakofler et al. (2003) communication in critical situation shifts from explicit to implicit. Besides that, the decision making in these situations is typically based on less than certain information. This uncertainty and unclarity may in itself be a source of stress.

Stress in training

As mentioned, a manageable level of stress increases learning performance and preparedness for future re-exposure. This principle has been applied in training for

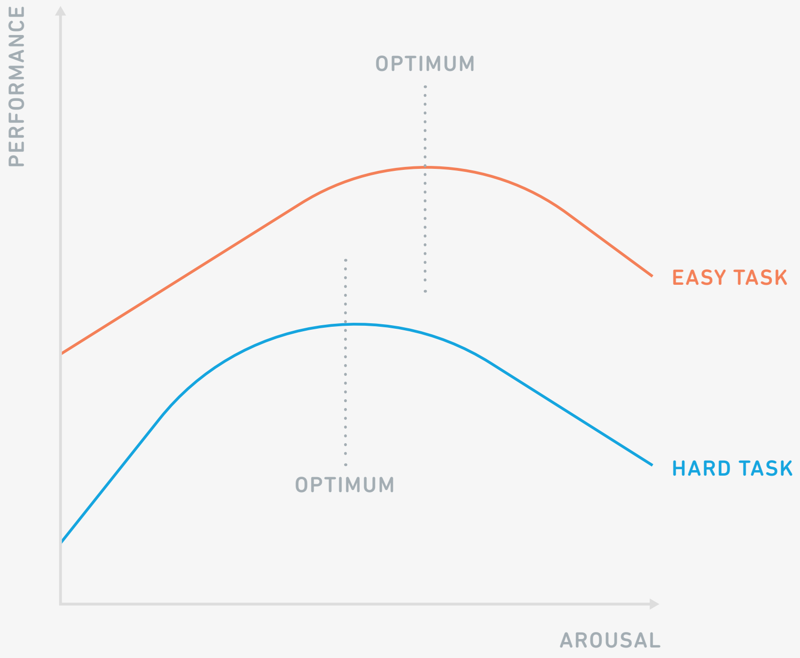


Fig.26 General arousal-performance patterns according to Yerkes-Dodson law

critical situation. For instance, a VR simulation targeted towards aircraft passengers for in cabin fire and evacuation, was aimed to reduce the chances of 'cognitive paralysis' in real world situations, by incorporating stress inducing stimuli such as smoke (Chittaro, 2012). However, anxiety (as a potential result of stress) is potentially detrimental for performance: during clinical nursing simulations, higher anxiety has been shown to result in lower performance (Gantt, 2013). This effect was much more present in practical simulations than in tutorial and discussion based training.

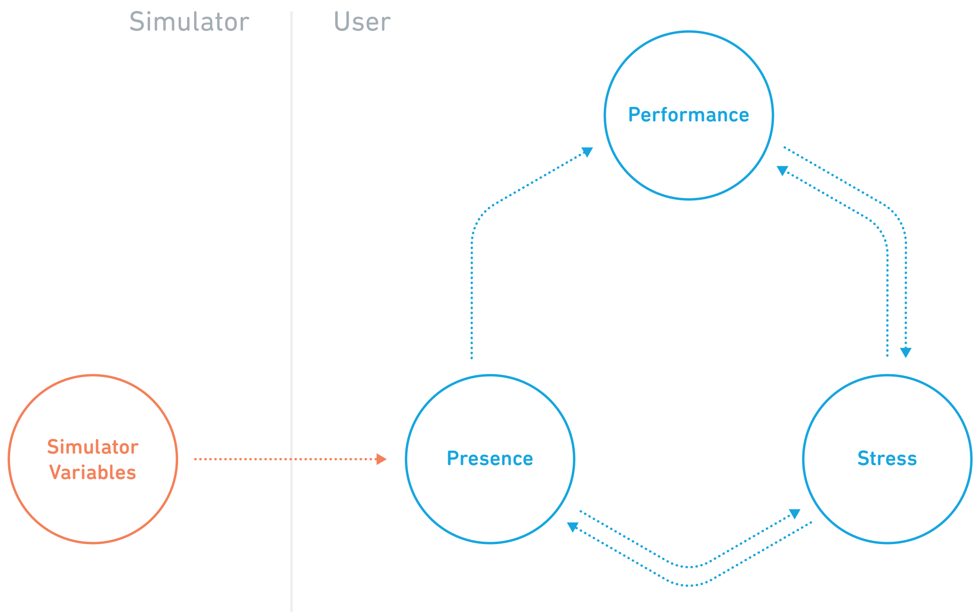


Fig.27 Relations of interest in the conducted study.

Research questions

The way stress factors or the unfamiliarity with (non-textbook) emergency scenarios seem to influence peformance begs the question: what does a simulation training need to entail to be optimally effective in its preparation for real-world emergencies? Little research has been done on how the level of abstraction of a simulation training affects the stress-response and performance of the trainee, both during the training and subsequently upon encountering a real-world emergency.

A large portion of the potential brought by AR and VR technologies to the CSST department lies in the ability to generate a sense of presence in a wide variety of virtually simulated contexts and situations (Lign et al., 2014, Diemer et al., 2015), theoretically allowing for a closer approximation of the unpredictability and contextually induced stress of an emergency.

To evaluate the value (and potential necessity) of VR as a simulation tool in the CSST context, a user study was conducted in which traditional simulation training was compared to VR simulation training, with a focus on stress, performance and presence (see **Fig.27**). The research is summarized in the 'Research' section, and the full case study is documented in the research paper in Appendix C.

Methods & Technologies

THERE ARE MANY WAYS IN WHICH STIMULI CAN BE SIMULATED AND INTERACTIONS CAN BE FACILITATED. THIS CHAPTER STUDIES WHICH METHODS AND TECHNOLOGIES HAVE POTENTIAL FOR APPLICATION IN THE CONTEXT OF CSST AND THIS PROJECT

Criteria

While the primary evaluation of technologies and means of simulation will be done during user studies, on the right several criteria by which solutions are assessed for their potential are listed.

Note that properties like immersiveness and presence are left out, as they will be investigated in the user study. Also, most of these are criteria that have no absolute metrics: the solutions are different enough that it is impossible to compare specifications.

- **Fidelity:** How rich and refined are the stimuli generated?
- **Versatility:** Can this solution be adapted (dynamically) to serve a range of simulation goals?
- **Cost:** What are the fixed and running costs for this solution?
- **Interactivity:** To what extent does this solution enrich how the user can act within the simulation?
- **Integration:** Does the solution suit the existing context, training programmes and way of working?

Physical models

To closely approximate the physics and technical properties of aviation emergencies, often physical models are used. At CSST this includes things like door trainers (see **Fig.28**), Cabin Emergency Evacuation Trainers (CEETs, see **Fig.29**), and smaller setups for training for CPR and lithium battery fires.

It is hard to classify all types of physical models that can be used in simulations, but it is useful to go over the considerations that play a role in their implementation.

Evaluation

Fidelity
Physical objects can go far in simulating the tactile and physical properties of real-life situations. However, as a simulation scales it becomes increasingly difficult to have control over how everything behaves. Furthermore, because of the physical nature, safety considerations and feasibility limit what is possible. In the case of the simulators at CSST, many contextual variables are left out.

Versatility
Many of the simulators have a number of programmable options to simulate different scenarios. However, because of the aforementioned limitations, as well as the fact most simulators are used for decades without ways to fundamentally change the setup, variability is quite low. Most trainees are familiar with the possible scenarios from previous training.

Cost
The more elaborate setups are a hefty investment. A door trainer, of which one is required for every aircraft type flown, costs several hundred thousands euros. Increasing versatility and the amount of simulated context (movement, smoke, etc.) makes these amounts go up significantly.

Fig.28 Door trainer in use at KLM CSST

Fig.29 CEET by EDM for Xiamen Air (EDM, 2015)

Interactivity

The interactions that are simulated are technically close approximations of reality. However, most things happen within the predetermined line of events of the simulation and feedback to the user's actions is often of limited richness. For instance, in the CPR training the dummy has a preprogrammed course of events and response to the actions of the participant.

Integration

A lot of the training is currently build around these simulation setups, and in that sense they are well integrated. However, the trainers have made clear that these setups are somewhat limiting their teaching goals. For instance, they would like to simulate very specific scenarios of their choosing to make certain points, which requires a high degree of versatility.

Virtual Reality

Virtual reality (VR) typically refers to technologies using computer generated 3D environments that present a full or partial replacement of the user's actual environment when in use.

VR HMDs

The most common implementation of VR in the consumer market is through head-mounted displays (HMDs). These are headsets that through one or more displays and lenses present the user with a stereoscopic image.

Variables

Displays

VR HMDs come either with one or two embedded displays (see **Fig.30**), or allow the mounting of an external display (e.g. a smartphone, see **Fig.31**). The former has the benefit of offering a tighter, more optimized integration, while the latter offers a more modular setup. When a smartphone is used, additionally, computing power and gaze tracking are completely embedded, allowing for a portable and wireless setup.

Abrash (2014), of the Steam VR team, proposed a set factors that he claims are essential for creating a significant amount of presence.

Displays should have a sufficiently high pixel density (at least 1000 x 1000 per eye, according to Abrash), as the picture fills the majority of one's field of view. Additionally, Abrash emphasises that the pixels should refresh quickly and simultaneously (low persistence, refresh rate above 95hz and the use of global display). Not reaching these specification has the potential to induce motion sickness. For the same reason, the frame rate of the simulation should be high (Waters, 2015).

Field of view

Human being have a binocular field of view (FOV) that is approximately 200° wide and 135° high (Dagnelie, 2011). To approximate this, and include peripheral vision in VR, the HMDs make use of optics, scaling and distorting the display's image to fill a large portion of the retina. At this moment, dedicated VR HMDs like the Oculus Rift and HTC Vive reach a FOV of 110° (see **Fig.32**), while smartphone based solutions typically offer around 60° (recently increasing up to 100° (Whitwam, 2016)). Lin et al. (2002) found a larger field of view increases presence and decreases motion sickness. Abrash (2004) recommends at least 80° to get a sizeable degree of presence.

Fig.30 Oculus Rift (Oculus, 2017)

Fig.31 Google Daydream View (Google, 2016)

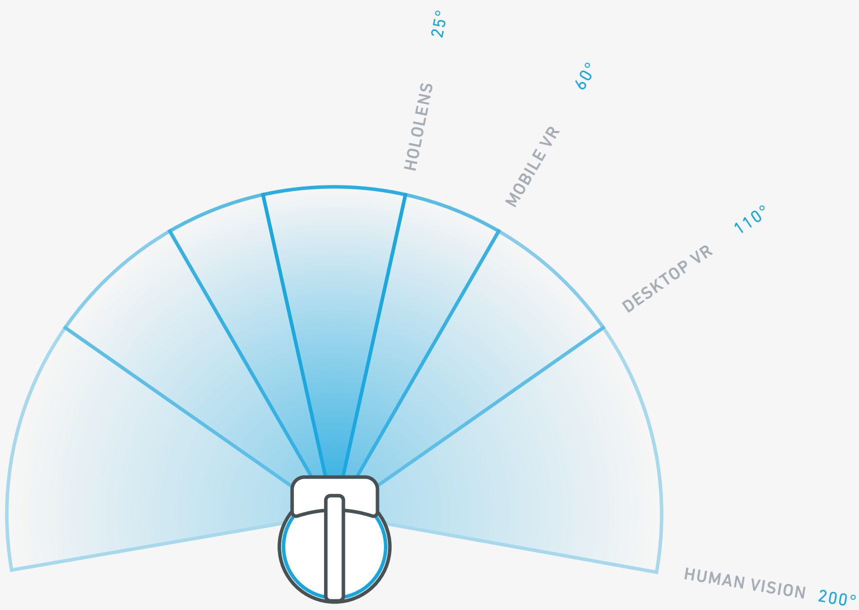


Fig.32 Fields of view of humans and typical VR and MR solutions in 2017

Evaluation

Fidelity

The complete replacement of the user's visual input makes VR potent in creating rich, immersive experiences. While generating stimuli with the level of refinement our eyes can discern is not possible with current technologies, research shows the technology is effective in eliciting emotions (Ling et al., 2014) and the feeling of presence (North & North, 2016). However, things like human actors are difficult to simulate. To solve this, 360° video might be used to create photorealistic content (albeit with a somewhat limited interactivity).

Versatility

Visually, almost everything is possible in VR, as long as a way is found to programme it. Furthermore, with the introduction of randomness and digital variables an almost infinite amount of scenarios can be generated computationally. That being said, making sure each scenario works and has a realistic progression of events can be a laborious development effort.

Costs

With high-end room-scale VR being available for under 2000 euro (all hardware included), it is a cheap way to gain access to a versatile array of simulations. Software development costs are present, but likely low compared to the costs of new hardware development. Additionally, after development the created software is easily scalable and replicable.

Interactivity

VR solutions differ in the interactions that they enable, and the interaction options are discussed in the Interaction & Feedback section. In general, it holds true that it is difficult but possible to simulate the physicality of interactions in VR, and the interaction refinement is somewhat limited. However, depending on the used setup, VR can be very natural and intuitive in its use of movement and space in its interactions. The design of these interactions is challenging, as poorly designed movement can induce motion sickness.

Integration

VR solutions are somewhat isolated and can offer experience with limited use of space and resources. Its versatility also means it can adapt to the changing requirements of the training programmes. A large challenge is the social and collaborative nature of the training, as HMDs cause people to be closed of from their surroundings. Collaborative (telepresence) VR solutions exist, but are not at the same fidelity as real-life contact.

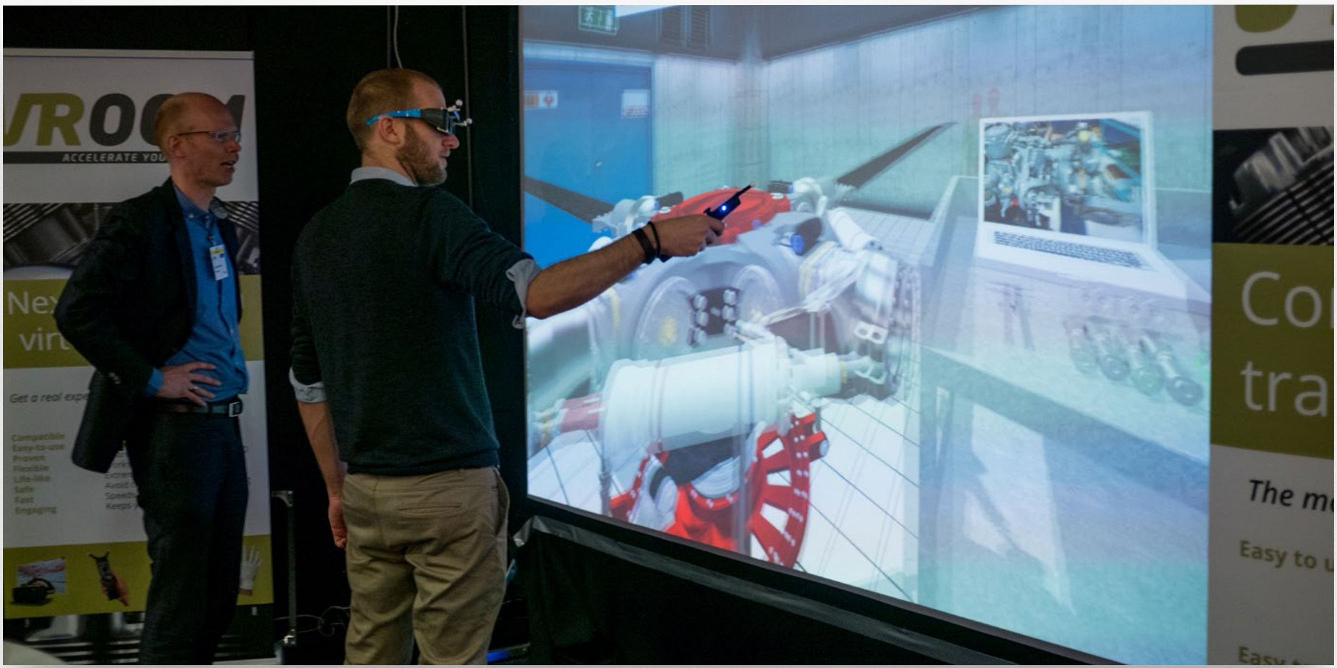


Fig.33 Active Shutter 3D projection with head and hand tracking used by VROOM at Virtual (R)evolution 2017

VR CAVEs & Powerwalls

An alternative to VR via HMD are CAVEs (Cave automatic virtual environment) and powerwalls, where the virtual environment is projected onto one or multiple surfaces. Many of these incorporate head tracking and active shutter 3D glasses (quickly flickering between the left and right eye views in sync with the projection) to create a sense of depth and space. Benefits of this approach over HMDs are that it allows you to see yourself and your physical surroundings (including other people), and latency issues (such as motion sickness) are reduced (Visbox, 2016a).

Variables

Resolution

Resolution can be higher than currently is possible with HMDs, as there is much more space available. As long as the computer running the simulation is powerful enough, with enough projectors a lifelike resolution can be realised.

Size & FOV

The FOV is largely determined by the sides on which a projection is present. A powerwall only has one active side, while most CAVEs have four (floor, and three walls).

Fig.34 VR CAVE projecting Aircraft Interior (Bali & Fisher, 2016)

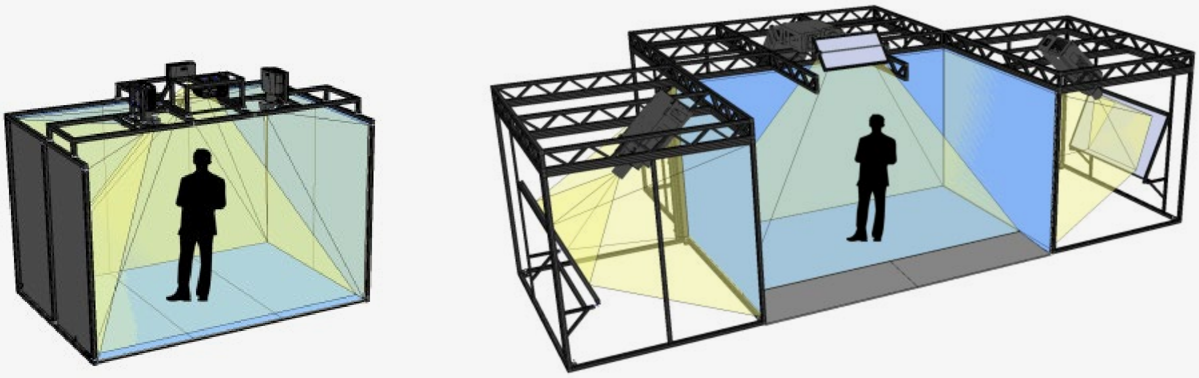


Fig.35 Visbox Viscube M4 and Viscube C4-4k respectively (Visbox, 2016c)

Technically it possible to project on every side of a room, but this seems uncommon.

Projection source

Projections can be done inside the CAVE or come from outside the CAVE (see **Fig.35**). The former is much more compact, cheaper and can be done in existing rooms but has the issue it causes the people present in the space to cast shadows. The latter doesn't have this issue, but costs more money and space.

Evaluation

Fidelity

Visually, a CAVE setup has almost the same fidelity as HMD VR, possibly with higher resolution, but likely a more limited total immersion.

Versatility

Versatility of CAVEs is similar to that of HMD VR, but is a bit more limiting in terms of movement and full immersion. On the other hand, the ability for other people to be present in the CAVE (although not with correct perspective) increases the possibilities for social and collaborative scenarios.

Costs

Powerwalls and VR CAVEs cost a quite a bit more than HMD VR, because of the extensive hardware requirements and lack of consumer products in the category. For instance, the VisCube C4 can cost upwards of 260.000 USD (The National Science Foundation, 2016). Development efforts are similar to that of HMD based VR, with integrations with popular game engines (e.g. Unity) available (Visbox 2016b).

Interactivity

Interactions based on movement and object tracking are possible in similar ways as in HMD VR, but possibilities for the substitution of physical objects are very limited because the projections don't typically overlay the objects present in the CAVE.

Integration

CAVEs and powerwalls are less portable, compact and scalable than HMD VR solutions, and have similar required development effort. Their potential benefit lies in creating fully digital simulations with a low barrier of entry (the active 3D glasses don't isolate and are easy to put on), whilst retaining a somewhat social and open teaching setup.

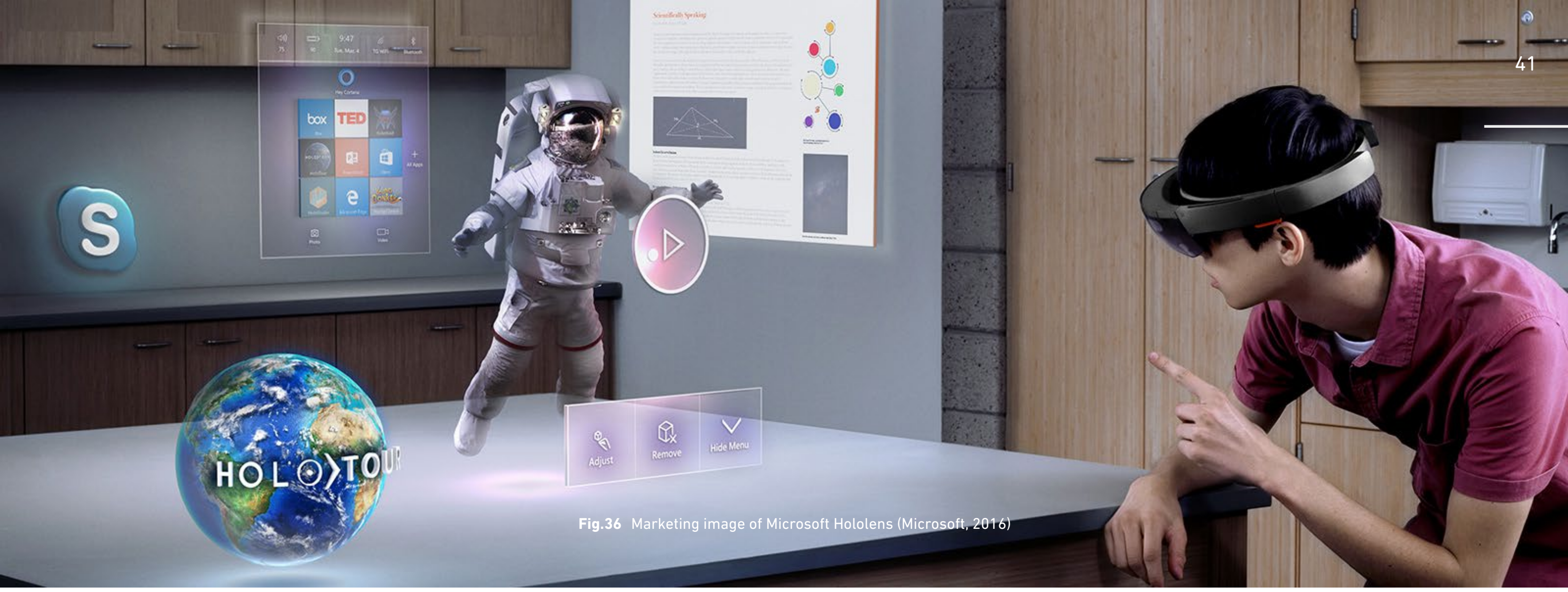


Fig.36 Marketing image of Microsoft Hololens (Microsoft, 2016)

Augmented Reality

Augmented Reality (AR) is the practice of overlaying digital layers on the user's current environment in real-time, most prominently visually. Similarly, the concept of Augmented Virtuality refers to the presence of physical entities in a virtual environment.

Variables

Augmented and Mixed Reality

Mixed Reality (MR) is the term often attributed to the practice where both are combined, and virtual and real elements co-exist in the same space, in the user's perception. In some cases this distinction becomes somewhat arbitrary, so in this case AR will refer to overlays without 3D position and integration in the physical environment, whereas MR overlays do have those properties.

Fig.37 Metavision Meta 2, with a 90° FOV (Metavision, 2016)

Form factor

AR / MR can take the shape of an HMD to overlay a projection on top of the user's natural view of the environment. These solutions are optically seethrough, which can be achieved using a number of technologies such as diffraction grating (Microsoft Hololens), prisms (Google Glass) and light fields (Magic Leap) (Baya & Sherman, 2016). HMDs can both be tethered (e.g. Meta 2) and standalone computers (e.g. Hololens).

Alternatively, AR / MR can be achieved through video passthrough, meaning a camera image and the virtual overlay are combined and presented on an opaque display. Typically, to keep the connection between the user, the camera and the environment, this takes the shape of a portable device such as a smartphone or tablet.

Field of view

AR / MR HMDs have historically had limited FOV. Google Glass can be seen as 'display' in the corner of your eye, while the FOV of the Hololens at 25-30° is similar in size to 15" computer monitor at normal viewing distance. However, solutions that are in the process of being released to developers, such as the Meta 2 (see **Fig.37**), offer FOV above 90°. Sharpness is, like in VR, a tradeoff between absolute resolution and the FOV.

Fig.38 Handheld AR using camera overlay and tracking marker (Chin, 2013)

Spatial awareness

Because AR / MR solutions are typically less bound to a specific location than desktop VR, they often have spatial mapping functions integrated. The following technologies may be used, often multiple at once:

- **Camera (+ computervision):** from a 2D camera image objects and their position may be recognized
- **Gyroscope, accelerometer and magnetometer:** these sensors (often combined in an Inertial Measurement Unit (IMU)), often present in smartphones, respectively measure radial acceleration, linear acceleration and magnetic field. Combined they can track the device's orientation and acceleration relative to the world.
- **GPS:** This is often used to roughly estimate the user's position in the world. This position can be refined through technology like beacons and optical tracking (see Interaction & Feedback section).
- **Depth camera (+ spatial mapping):** HMDs like the Hololens, as well as some phones (e.g. the Lenovo Phab 2 Pro running Google's project Tango) have depth sensing cameras. This can for instance be achieved by using stereo cameras or by projecting light into the world and measuring how it responds ('Time of Flight' and 'Structured Light' methods) (Google Project Tango, 2017). Combined with the movement sensors and computer vision algorithms, a digital 3D representation of the space and the user's position therein can be made. This is a primary enabler of MR overlays with a fixed world position.

Evaluation

Fidelity

In its current state, high-fidelity MR / AR is not feasible. The handheld video-passthrough solutions have the issue of not being immersive, while the optical-passthrough options have limited FOV and can only add light (a black projection becomes transparent). Still, technologies that consistently place virtual content in the world (e.g. Hololens) can to a degree result in a suspense of disbelief and a resulting immersion, for which standardized questionnaires are proposed (Georgiu, 2017).

Versatility

While in AR / MR can make additions to the real context of a user, they are very limited in the altering and removal of real-world objects. The technology enables interaction with real-world objects, and collaboration among multiple users, but a virtual interaction typically doesn't generate real-world feedback. This makes it versatile and applicable for certain contexts and less for others.

Costs

Costs wildly vary, but typically higher spatial awareness and FOV come at a cost. Smart phones with simple AR abilities are universally available, but very limited in their use. Standalone solutions like the Microsoft Hololens offer good spatial awareness but low FOV and processing power at around 3000 euro. Industrial solutions like the Daqri Smart Helmet offer a larger field of view at a higher cost (Dolcourt, 2016). Tethered solutions can be found below 1000 euro, but require a separate computer and have limited freedom of movement.

Interactivity

Whilst using MR / AR, interactions with real-world objects are possible, but incorporating them remains a challenge. The Hololens employs an interaction model based on gaze, gestures and voice control (Microsoft Hololens Team, 2016). In general, the challenges from interacting in VR are present here as well, and similar technologies (See interaction feedback section) can be used to expand the possibilities.

Integration

According to Helmerhorst (2017), integration of AR at KLM would be more challenging than that of VR, because the technology needs to be aware of the context in which it is employed. As such, the development efforts are predicted to be higher. On the other hand, the more open and collaborative nature of the technology makes it more suitable for the teaching style at CSST.

Auditive stimuli

Sounds could be used for multiple goals in simulations, including instructing, setting mood, giving feedback and simulating the environment. Sounds can be directly send into the ear, or have a spatial location (either physically or virtually through spatial or stereo headphones).

Evaluation

Fidelity

Audio has been shown to be able to elicit emotional response on its own, and enhance visual simulations (Brinkman et al., 2015). Both 3D audio and stereo audio can give a user an idea of the location of the audio source (especially in combination with user movement). According to Brinkman, 3D audio doesn't offer a significant increase in presence over stereo.

Versatility

Audio is potentially an important aspect of the experience of being in an emergency situation, but hearing is not really covered in most of the teaching (apart from human language and alarm sounds). However, it is easy to add and change audio generated during a simulation and is thus a useful tool in increasing the realism of the simulation.

Costs

Hardware costs are negligible. The costs of recording, synthesising and implementing sounds depend on the fidelity. Using sound primarily as a source of information about what is going on is easily implemented, while creating a dynamic and rich soundscape that responds to user interaction will take more effort.

Interactivity

Besides potentially increasing the user's understanding of his / her environment and situation, sound feedback can increase the coherence of the user's perception of the virtual environment (Müller-Tomfelde, (2004).

Integration

While the technical implementation of audio in simulations is not that challenging, it hasn't been a part of the CSST programmes. This thus requires a study into what sounds would be audible in certain real-life emergency situations.

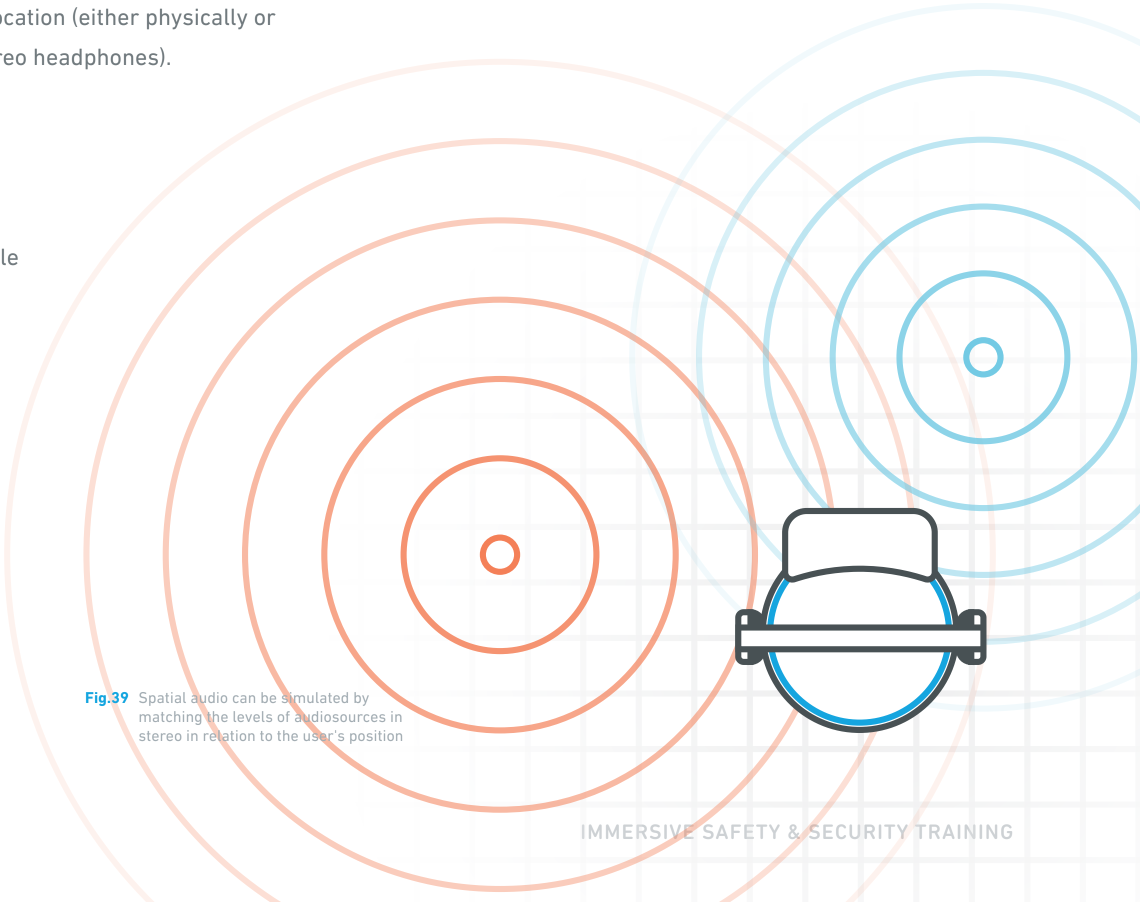


Fig.39 Spatial audio can be simulated by matching the levels of audiosources in stereo in relation to the user's position

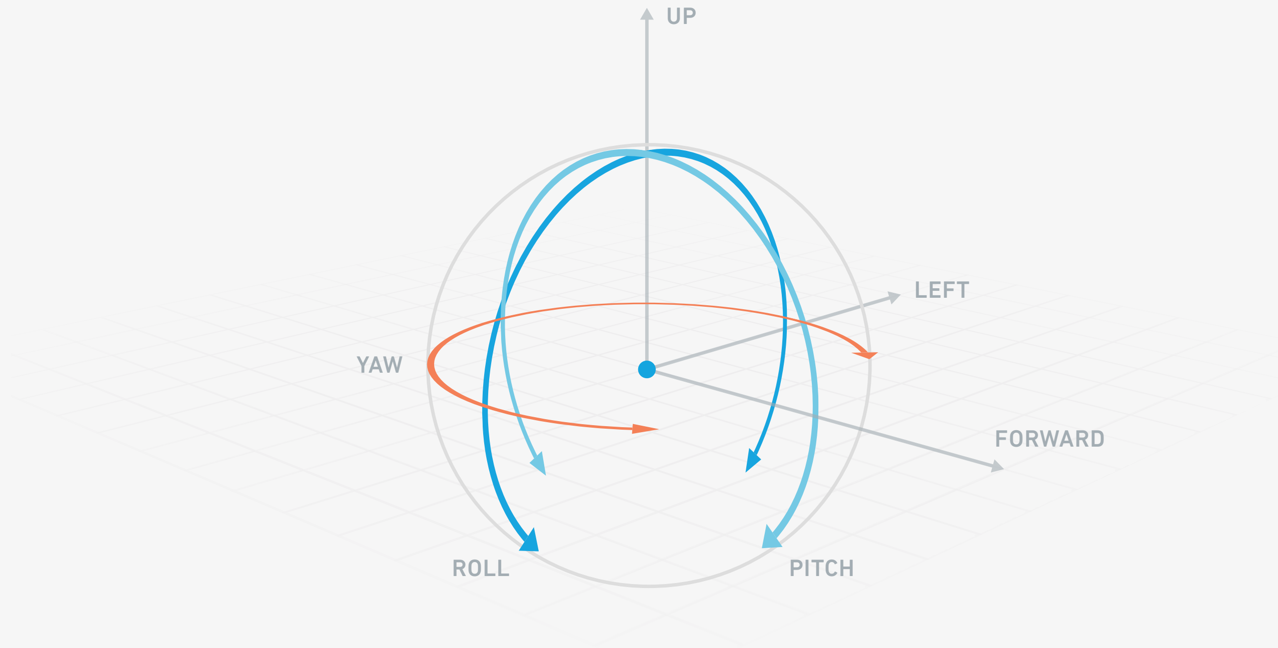


Fig.40 6 possible degrees of Freedom in 3D space

Head, gaze and object tracking

If a simulation incorporates augmented virtuality, especially with HMD VR and MR, knowing the user's head position and gaze direction is important. Similarly, to incorporate dynamic physical objects (e.g. controllers or custom accessories), their position and orientation has to be known.

Variables

Degrees of freedom

The degrees of freedom (DOF) (see **Fig.40**) describe along which axes and rotation vectors a user can move. To be considered VR, a solution typically at least needs to enable a user to change his / her gaze direction (i.e. 3 DOF, namely roll, pitch and yaw). To physically move around through a virtual environment, all 6 degrees need to be enabled.

Tracking Technologies

IMU

IMUs are almost always used in VR and MR headsets to track gaze direction, because it is not dependent on the environment of the user (besides the Earth's magnetic field and gravitational pull). However, the accelerometer is not suitable for accurate position tracking: to derive position the linear acceleration has to be double integrated, which cause drift to grow quadratically (Vincent, 2013).

Spatial mapping

Integrated depth sensing cameras (as present in the Hololens, see AR section), often with the help of an IMU, build a digital 3D representation of the device's environment. Based on the incoming depth data gaze and position can be derived from comparing it to the existing 3D model.

Technology	Gaze tracking	Position tracking	Spatial awareness
IMU	Yes	No (too much drift)	No
Spatial mapping	Yes (less accurate)	Yes	Yes
Optical trackers	Yes	Yes (sub mm accuracy)	Limited

Fig.41 Different tracking technologies

Fig.42 HTC Vive Lighthouse system working principle (van der Meer, 2015)

Optical trackers

Another way is to derive variable positions relative to specific known positions by placing trackers in a space. There are multiple methods to do this, but two typical approaches: making the trackers measure signals emitted from the tracked objects and vice versa.

The former is used by the Oculus Rift (consumer VR HMD) in the Constellation system, where the headset and controllers emit infrared light from fixed points in fixed patterns. The position of these lights is registered by the camera in the tracker, thus making accuracy limited to the camera's resolution.

The latter is used by the HTC Vive in the Lighthouse system, where per tracker two spinning lasers rotate IR light planes through the room (see **Fig.42**). IR sensors on the tracked headset and controllers then register the times at which they register the incoming beam. By syncing the clocks in the system the vectors between the lighthouses and the sensors are derived, and by comparing these vectors the orientation and position of the tracked objects are derived.

Evaluation

3 DOF Gaze tracking

Fidelity

As long as the user remains stationary, gaze tracking can be used to accurately present a user with the view corresponding with the direction he / she is looking in. This would establish a degree of presence.

Versatility

The solution has only one purpose, but can be applied to enable gaze based interactions. In VR, the lack of positional tracking would complicate movement. Movement may be done virtually, but the resulting conflicting stimuli may cause motion sickness (Templeman et al., 1999).

Costs

IMUs are very cheap and integrated in most HMDs and smartphones.

Interactivity

As mentioned, this solution in itself only enables gaze / orientation based interaction (look at an option / action to perform it). Furthermore, it enables observation of the surroundings, which can inform the decision making.

Integration

In terms of hardware, IMUs are typically integrated in VR / AR solutions. For software development, the use of 3 DOF gaze tracking requires the content to have either 3D positions (e.g. 3D rendered environments) or radial positions (e.g. 360° video).

Fig.43 Manus VR does hand tracking with integrated sensors (Manus VR, 2015)

6 DOF Head tracking (+object tracking)

Fidelity

Because the introduction of positional tracking decreases conflicting stimuli upon locomotion between the virtual and real environment, this is likely to increase presence (both VR and AR) and decrease motion sickness (mainly VR). Tracking physical objects in space to interact with the virtual environment increases the tactility and physicality of the simulation experience.

Versatility

In VR, 6 DOF tracking enables natural locomotion and interaction with a space. In the case of AR, the increased spatial awareness enables virtual and real objects to coexist in a 3D space. This increases the versatility significantly.

Costs

Costs depend on the solution, and are often integrated. Trackers with sub-millimeter accuracy are available between 100 and 1000 euro in consumer products. However, the trackers used in industrial systems such as VR Caves are typically much more expensive.

Interactivity

6 DOF tracking is almost a prerequisite for having spatial and physical interactions in a AR / VR simulation. It enables a lot of simple interactions (e.g. gazing, walking, moving objects), but may lack the refinement for others (e.g. finger gestures)

Integration

6 DOF tracking is somewhat harder to implement: it may require dedicated hardware setups in spaces (i.e. trackers) and complicates the production of content (e.g. 360° video doesn't work as it doesn't have 3D data)

Body tracking

More refined interactions, or interactions making use of the user's postures are enabled by motion capture. Most methods for this make use of similar technologies and principles as object tracking and spatial mapping, but the algorithms are catered to things without a consistent shape (i.e. human body parts). Popular consumer solutions, like the Microsoft Kinect (full body tracking) and Leap Motion (hand tracking), sense depth using the structured light method, project IR light and measuring its placement on the surface it is cast on using a camera. The resulting 3D data are compared with models of the human body using machine learning, estimating the skeletal structure of the tracked body part (see **Fig.44**). Alternatively, motion capture suits can be utilized, either with fixed tracking points or integrated sensors (see **Fig.43**).

Fig.44 Leap Motion mounted on HMD for hand presence in VR (Leap Motion, 2017)

Evaluation

Fidelity

The interactions enabled by body motion capturing products like the Microsoft Kinect have the potential to be more intuitive and enjoyable than conventional human-computer interactions, and contribute to overall presence (Francese et al., 2012).

Versatility

While technically challenging, capturing body motion enables virtual simulation of a lot of refined physical interactions. However, this type of interaction is not that common or important in the CSST training programmes. The challenges lie either in the cognitive decision making process or the performing of more crude physical actions (e.g. using a fire extinguisher or pulling a lever). These technologies might be useful in some, but not all simulations. A potential alternative use is using it to capture the performance of participants during training.

Cost

Again, the consumer solutions available are available at low cost (around 100 euro), with limited accuracy. Motion capture suits and the required setup are significantly more costly. However, development efforts may be high, as explained below in 'integration'.

Interactivity

As mentioned, the technology enables a lot of natural movement based interactions using the entire body. However, for the most part interaction with virtual space still lacks tactile feedback. Some suit based solutions do however incorporate haptic feedback or ways to constrain joints.

Integration

There are a number of challenges in integrating body tracking in CSST. Foremost is the high development effort, as the data from an entire skeletal model is less clear in meaning than registering a user pressed a button. Furthermore, if a capturing suit is utilized this is likely to increase the threshold of entering the simulation experience for most participants.

Speech

In CSST a large portion of the training comprises what to say and how to say it in certain situations (communication with crew, unruly passengers, health emergencies, instructing passengers). Speech recognition and natural language processing may thus be important in incorporating a virtual layer.

Speech Recognition

Speech recognition is the practice of computationally deriving text from audio recordings of spoken words, by analysing the soundwaves over time. Because this is typically done using machine learning, which requires large datasets, speech models and processing power, this process often happens in the cloud. It can also be done offline, but often at lower accuracy.

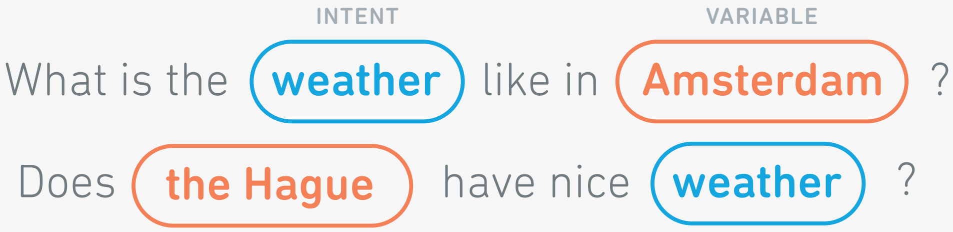


Fig.45 Recognising phrases based on intents and variables

Natural Language Processing

When it is recognized what a user said, and the software needs to respond to this in some way, the first step is to understand what the user said, and what the intent is. When there isn't a predefined set of commands (e.g. 'turn the lights on'), natural language processing is used, which uses machine learning to derive the grammatical structure, intent and variables from a phrase (see **Fig.45**). The intent and variables can then be used to generate a response.

For both speech recognition and natural language processing existing solutions are available, often developed to create bots for chat applications (e.g. WIT.ai, Microsoft Bot Framework) and integrations with personal assistants (e.g. Amazon Alexa, api.ai).

Evaluation

Fidelity

Speech is one of the most natural ways to express, and very common in CSST. However, AI is at this point not at the level that it can understand and respond at the level humans can. Therefore it will almost always be obvious that an interaction is not fully real, which will discourage people from speaking freely and naturally.

Versatility

Theoretically the incorporation of speech would contribute to almost all simulations and scenarios, but it is only relevant if this can be dependably be achieved at a high level. Right now this isn't the case for the most part.

Costs

Hardware costs are low or non-existent, and existing free platforms make it quite easy to develop simple speech based human-machine interactions. However, the development effort to get to a higher level of complexity and understanding is significant, if at all possible.

Interactivity

Interactions become increasingly complicated as an conversation progresses, due to the increased relevance of context.

Integration

For a portion of the trained procedures and simulations to work in VR or AR, either speech recognition is required or the social interactions have to be dramatically simplified to a fixed set of expressions and story lines. The former, as indicated, would in most cases require extensive development. The latter could be very useful in making practicing more accessible, but doesn't quite reach the level of depth that is currently present in the social aspects of the simulations.

Conclusion

All mentioned technologies have cases in which they are the most suitable means of simulation. If not too restrictive, physical models can recreate a vivid tactile experience. However, in many scenarios the versatility of VR and AR is much more relevant. HMDs can provide a contained visceral experience, but are often an obstacle in collaboration. The good news is that solutions can be modularized and combined freely in many cases.

Fig.46 Girl riding bike wearing a Samsung Gear VR mobile HMD (Voortman, 2016)

3 | SCOPE DEFINITION

Fig.47 Lake Louise Autumn (Hauser, 2016)

Context Selection

THE INITIAL SCOPE IS TOO BROAD TO CREATE SOLUTIONS THAT ARE SUITABLE FOR COMPARISON IN BOTH THE RESEARCH TRACK AND THE CREATION OF A DESIGN PROPOSAL

This warrants for a narrower definition, which is done by selecting the learning goals that the final design should serve and picking a specific section of the training programme to target.

While this project aims to propose a general approach for the implementation of VR, AR and / or MR at the facilities, a start is made by focusing on a specific part of the programme. The topics of the training programmes are assessed for suitability with the following criteria:

- **Current Realism:** To what extent does the current simulation cover the aspects that make the emergency scenario challenging (stress, collaboration, physical aspects)? If this is low, this means improvement is critical.
- **Uniqueness to Aviation Industry:** To what extent are the topics in the training aviation specific? Otherwise, chances are existing solutions using VR / AR / MR exist.
- **Potential for improvement:** What is the clear potential for improvement that VR / AR / MR show in each simulation / topic? What can it do to serve either the participants or the trainers?
- **Feasibility VR / AR / MR:** How realistic is it that these technologies can successfully play a role in these simulations / topics? This is in terms of development effort, ease of integration within the training programme.

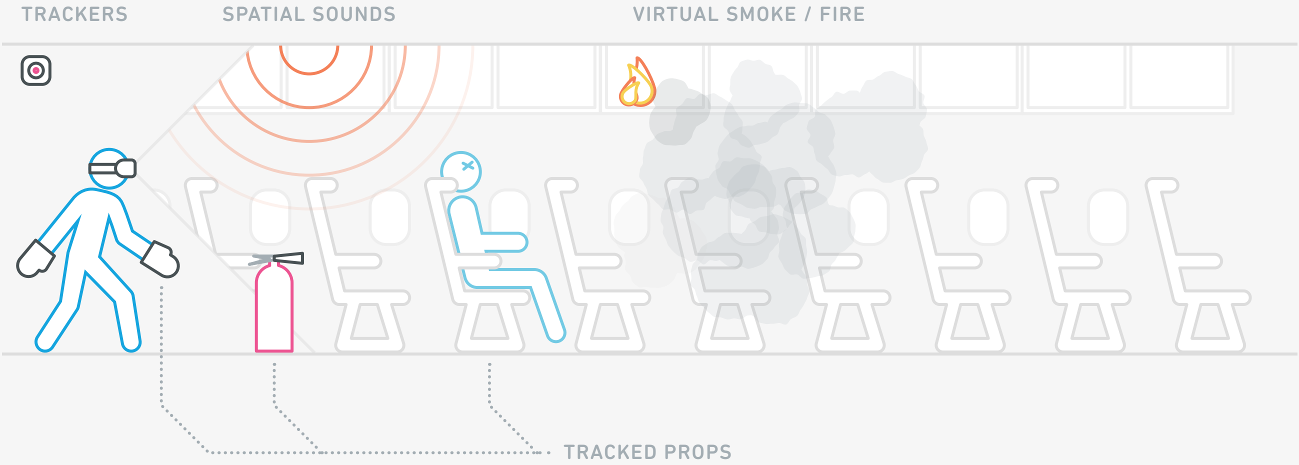


Fig.48 Sample implementation of VR in cabin fire fighting simulation

Fire fighting

Current Realism

The current simulations include smoke effects, and in one case actual (albeit controlled) fire. The situations are explained in advance and very little of the context (aircraft interior, people, alarms, movement) is included. The gear and utensils of the real-life scenario's are largely present and used during the exercises. Furthermore, some simulations include some role-play. All simulations are relatively brief, or interrupted upon mistakes. As such, the current simulations are an over-simplification of reality.

Uniqueness to Aviation

Firefighting is not unique to aviation, and some advanced VR training solutions are already on the market (e.g. RE-liON's redsuit (n.d.)). This context has some uniqueness here with the lack of in-depth training and limited available tools (e.g. drinks from the trolley may be used to cool burning electronics). This warrants a degree of inventiveness in the dealing with different scenarios.

Potential for improvement

VR / MR can contribute by making the fire fighting simulations less predictable and including more contextual stimuli like sound and smoke. Perhaps most importantly, it allows participants to make mistakes and experience the consequences of their actions throughout a lengthier simulation.

Feasibility

To assess the feasibility, sample scenarios of VR / MR implementation were developed. In the case of fire fighting it could have the following properties:

- VR Headset (with backpack) that is tracked in space, enabling you to walk around
- 3D tracked physical props (e.g. Halon, Gloves, Dummy) with virtual equivalent representations.
- Virtual effects (smoke, fire from random source)
- Spatial audio (alarms, panic, fire)
- Assignment to try to extinguish fire, then help evacuate a passenger

This seems quite feasible with current technology: object tracking sensors / systems are readily available, and most interactions are quite simple and centralized around specific objects (e.g. using the fire extinguisher). Furthermore, little is required in terms of complex animations and modeling to get the basic effect.

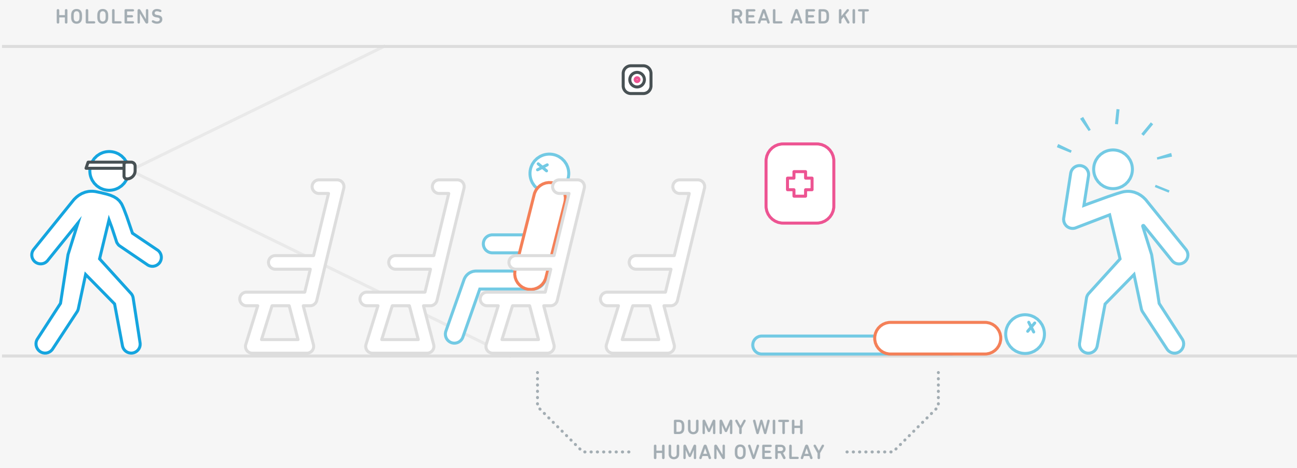


Fig.49 Sample scenario for simulating medical emergencies in AR

Medical Emergencies

Current Realism

Most medical training is currently theoretical (recognizing medical conditions, following procedures), but things like CPR have to be practiced on a dummy. However, this simulation is perceived as quite comical by most participants and never introduces the emotional pressure of bystanders and the impact of your actions altering someone's direct chance of survival.

Uniqueness to Aviation

First-aid and CPR training are largely standardized, and VR / AR versions are being developed (Semeraro, 2009) (Djajadiningrat, 2016). However, the context is somewhat unique due to limited availability of space, the need for communication with the cockpit and potentially small availability of immediate medical assistance.

Potential for Improvement

Potential for improvement lies in training participants to deal with the stress and emotional pressure of medical emergencies, and expand the exercises to coordinating actions of the team. The simulation would improve in quality if it were less predictable in both premise and the consequences of the user's actions.

Feasibility

Because medical emergencies typically require communication, interaction with people and the handling of more refined props (e.g. AED boxes), a mixed-reality sample scenario was selected for this context. It includes:

- One or more participants wearing MR headsets (e.g. Hololens)
- Aircraft interior, to create a physically representative space
- A CPR dummy with a real human as MR overlay. This dummy gets a surprise medical emergency, and has to be carried to an open area.
- Context of people being affected by the situation (e.g. husband / wife of patient)
- AED exercise with response of virtual people on your performance
- Interaction with dummy, AED box and through voice control

This is somewhat feasible since the interaction is focused around selected artifacts. However, getting the animations right could be somewhat laborious.

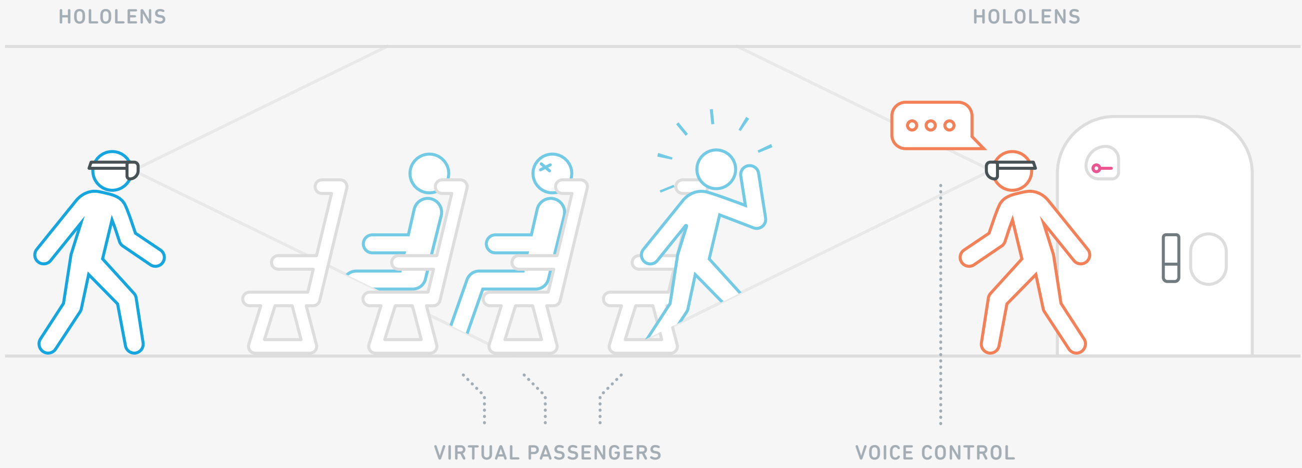


Fig.50 Sample scenario for MR Aircraft Evacuation Simulation

Evacuations

Current Realism

While the full cabin simulator with a crash scenario is pretty lengthy and does quite a lot to generate representative stimuli (turbulence, sound effects, lights, smoke, using the emergency slide). It also requires the active coordination and collaboration among the participants. While this form a visible source of stress, the simulation is somewhat lacking in how everything goes perfectly as planned: participants neatly line up to exit the aircraft, follow all instructions and little that happens is unexpected.

Uniqueness to Aviation

This context is very unique to aviation, although the activities have some similarities with crowd management simulations police units might do.

Potential for Improvement

The simulation can improve by simulating surroundings, decreasing the predictability of events and making the behaviour of the passengers more diverse and imperfect.

Feasibility

Because this training requires a lot of collaboration and interaction with the physical components in an aircraft, the sample scenario comprises:

- Multiple participants wearing MR headsets (e.g. Hololens)
- Virtual passengers in different states (e.g. trying to get out, behaving according to instructions or in shock)
- Interaction with passengers through voice control
- Simulated surroundings and effects (interior and exterior)
- Interaction with physical components, such as the aircraft doors.

This type of simulation would be pretty complex to create in terms of natural language processing, creating responsive behaviour in the virtual passengers and animating everything accordingly. It could be simplified into an interactive story format, with fixed decision points, but then the value over the current simulation would be very limited.

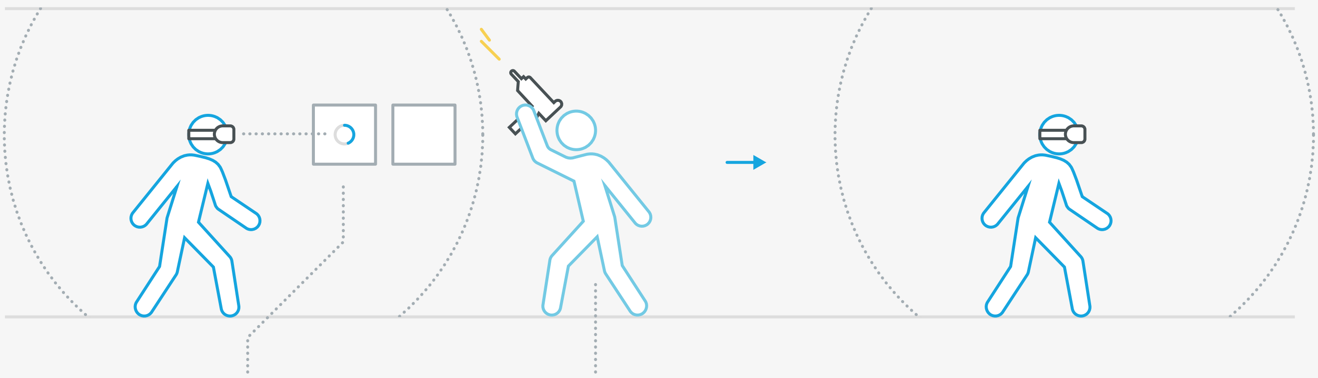


Fig.51 Scenario using VR in simulating a hijacking

Unruly Passengers

Current Realism

Actors and role play are utilized in playing out a wide range of possible scenarios. This covers both physical aspects and professional decision making. Despite the presence of a trained actor, the simulation fails to get to a point where things really escalate in a believable manner. However, some participants cited this part of the training as the most stressful.

Uniqueness to Aviation

While most of the social and self-defense skills trained are not unique to the context, the context itself impacts the courses of action and potential threats. For one, conflicts are almost always constrained by the aircraft itself, and help can only be sourced amongst passengers and the crew. Furthermore, in case of Hijacking, the aircraft itself is a potential weapon and means of extortion.

Potential for Improvement

This training possibly struggles with the cost and availability of resources that prevent it from being completely immersive. Immersive technologies could be used to allow for further escalation of conflicts, more elaborate and prepared acting and simulated context. This could improve the teaching of professional judgment.

Feasibility

Simulating the entire set of behaviours of an unruly passenger, and animating accordingly would be very challenging. However, because they mostly concern interaction with a single person, some of these training procedures can be simplified into a set of choices that are made in different points in time. This enables the interactive story format. In this sample scenario 360° videos are played on a simple mobile VR solution. In these videos, actors play out situations, where the observer is given different courses of action, between which she / he can select by gazing.

This approach is very simple to implement and a wide set of scenarios can be implemented simply by recording more videos. However, it may become limiting in the complexity of the interactions it allows: longer stories get exponentially more laborious to create, and interactions are limited to predefined options.

Category	Current Realism	Uniqueness	Potential	Feasibility
Firefighting	Medium	Medium	High	Medium
Medical Emergency	Low	Low	Medium	Medium
Evacuation	Medium	High	Medium	Low
Unruly Passengers	Medium	High	High	Low / High

Fig.52 Evaluation of the general contexts

Context Selection

The four categories are evaluated as listed above in **Fig.52**.

While according to these criteria creating an interactive story based training in VR for the unruly passengers and hijacking scenarios seems to have a lot of potential. And granted, this is a relatively easy way of creating a portable and scalable training (this could even be a expanded to an interactive story training platform within KLM). As such, I recommend KLM to look further into this direction in the development of their training programmes.

However, this direction does not match well with the goals of this project, of increasing the immersion and depth of the training. The approach would be severely limiting the amount and depth of the interactions that can be implemented. Instead **the firefighting context is selected as the focus of the research project.** While still quite a challenge, immersive technologies in this context have the potential for a degree of presence and progression in the scenarios that would otherwise not be possible.

For this reason VR is selected over AR for the remainder of the project, as it is more capable of fully controlling the perceived environment (without resource and physics related restrictions). It is also arguably a more matured technology with a less complex implementation (contextual understanding / integration in AR remains complex). That being said, AR does show promise for social and collaborative simulations.

Furthermore, the scope and goals of the design proposal are in part a result of the findings during research, and will in any case take a broader look at the application of VR than the one used during the research (see **Fig.53**).

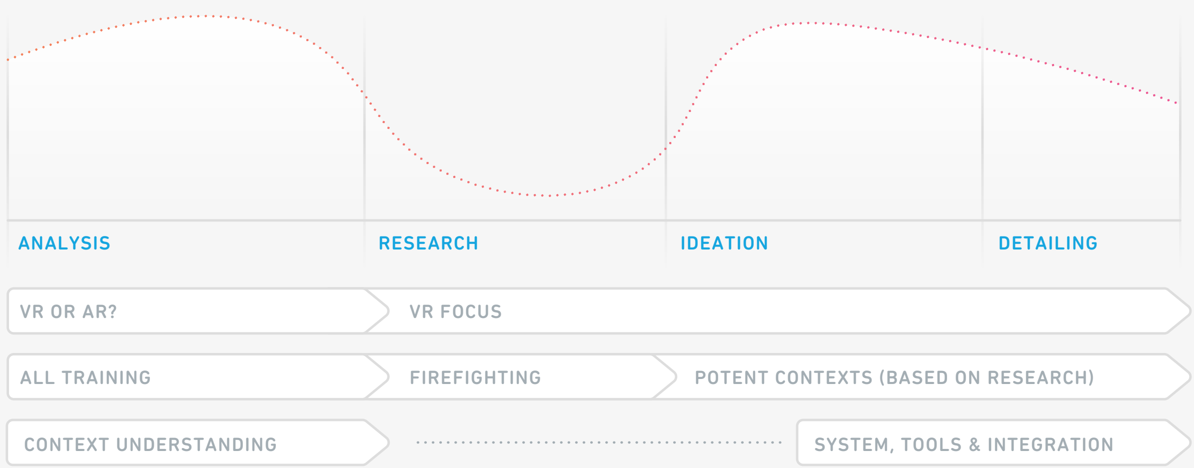


Fig.53 The project scope differs between the research phase and the one of the final design proposal

Learning goals

THE LEARNING GOALS LISTED BELOW ARE DERIVED FROM THE DIDACTIC NEEDS FORMULATED IN THE STAKEHOLDER ANALYSIS, BUT LIMITED TO THOSE THE TECHNOLOGIES OF INTEREST (VR IN PARTICULAR) HAVE THE POTENTIAL OF CONTRIBUTING TO. TO VERIFY THE FINAL DESIGN, IT IS IMPORTANT THAT THESE LEARNING GOALS ARE SOMEWHAT MEASURABLE, FOR WHICH SOME METRICS ARE ESTABLISHED.

Learning goal	Metrics
Serious and understanding attitude towards safety & security	› Presence in the simulation › Experienced emotions in simulation › Engagement with training programme
Professional decision making ability in real-world emergencies	› Performance under stress › Performance in new or unpredictable situations
Evaluating what goes wrong, and understanding why.	› Points of improvement that are picked up on during training › Performance improvement over time
Personally relevant training, learnings and reflection	› Degree of customization in training › Perceived value of learnings

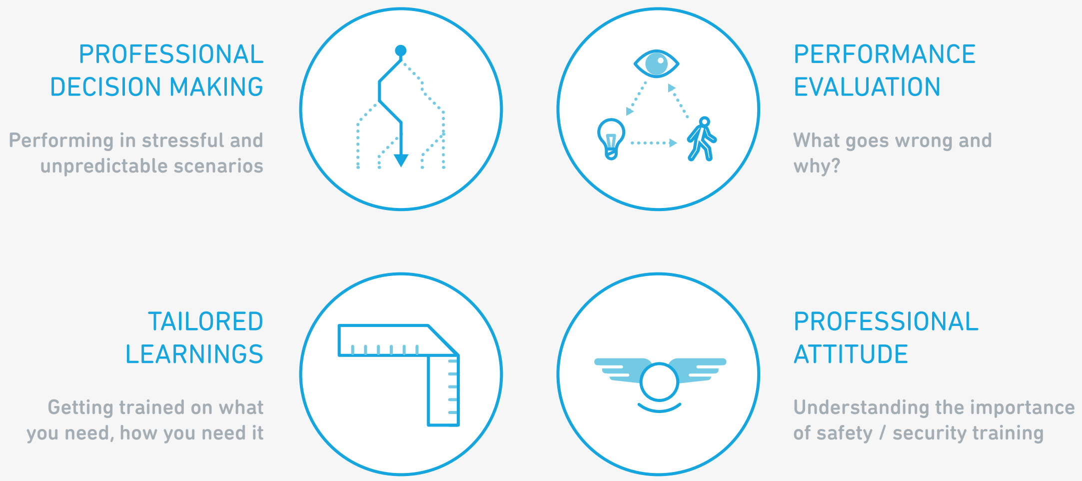


Fig.54 Learning goals that the design of this project aims to serve

4 | RESEARCH

Fig.55 Participant during user research, opening a virtual overhead compartment.

Preliminary Simulation Design

FOR THE USER RESEARCH A VR SIMULATION PROTOTYPE WAS BUILD. THIS CHAPTER CONTAINS ITS DESIGN AND UNDERLYING CONSIDERATIONS. THIS PRELIMINARY DESIGN ALSO SERVES AS AN EXPERIMENTAL STARTING POINT FOR THE FINAL DESIGN PROPOSAL (SEE 'SIMULATION DESIGN REVISIONS').

Goal

The goal for the prototype is to develop a VR cabin fire fighting simulator, in which the core of the fire fighting procedures of the CSST department can be executed by the user. This is done to be comparable to the fire fighting training as it is currently taught. However, the goal is to as closely as feasible approximate real-world fire fighting scenarios, not necessarily the traditional training itself. As such, the developed simulation should utilize the potential (uniquely) offered by the VR technology.

Approach

The approach taken for the design and development of the simulation is highly experiment- and iteration-driven: understanding how a designed environment or interaction paradigm feels and functions in VR, requires a degree of implementation and validation. As the digital nature of the development makes changes immediate, in some cases iteration cycles only take a few minutes. Besides this continuous testing, a research pilot was performed to verify the simulation as a whole with novice users (see appendix C).

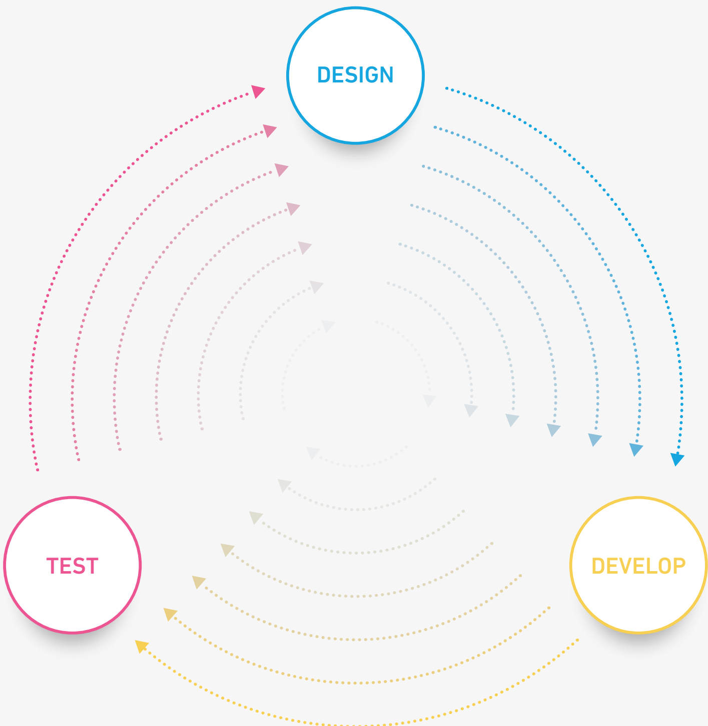


Fig.56 The design was created through rapid iterations comprising designing, prototyping and testing

Fig.58 HTC Vive HMD with included controllers and Lighthouse tracking system (HTC Corporation, 2016)

The HTC Vive (see **Fig.58**) was used as HMD, as it was the VR system with highest available fidelity, especially given its room scale tracking which allows for movement with 6 DOF. The Unity game engine was used for development (see **Fig.57**), as it provides highly visual ways of editing the virtual environment, as well as easy ways to implement functionality through both built-in tools and third-party libraries available on the Unity Asset Store (Unity, 2017a).

Fig.57 Unity logo superimposed over editor interface.

Fig.60 Fire fighting simulation room at CSST

Fig.59 Screenshot of seating area of virtual cabin

Environment

Most simulators at CSST include only a small section of the aircraft. In the case of the fire fighting training, it is a condensed combination of fire hazards including a toilet, two overhead compartments, 4 seats and a kitchen (with 4 predefined fire locations in total).

Instead, the VR simulation includes a 1:1 scale cabin (approximately that of a Boeing 737) through which the participant can move. This is done in an effort to:

- **Increase presence and perceived realism:** From the metal interior to the abundance of space, the original simulator has little resemblance to an aircraft. By creating a more representative environment, users may experience increased presence and a suspension of disbelief.

- **Incorporate movement, search and unpredictability:** In the traditional training, participants fetch equipment in advance. In reality, and in the VR simulation, equipment is stored and the time it takes to fetch it may influence both decision making and the outcomes. By simulating the entire cabin, fires can occur anywhere, rather than a fixed location.

Fig.61 Kitchen area in the front of the virtual cabin

Fig.62 Fire in seating area (edited)

Interior

In terms of interior, the virtual cabin includes 48 seats (with tables), 12 overhead compartments (with interactive doors) and doors and a kitchen area in the front. As little to no official 3D assets are available to KLM, and realistically modelling the interior would be very time-consuming, simple representations (of the aircraft, interior and equipment / props) were mostly modeled and in some cases sourced from 3D repositories.

Props

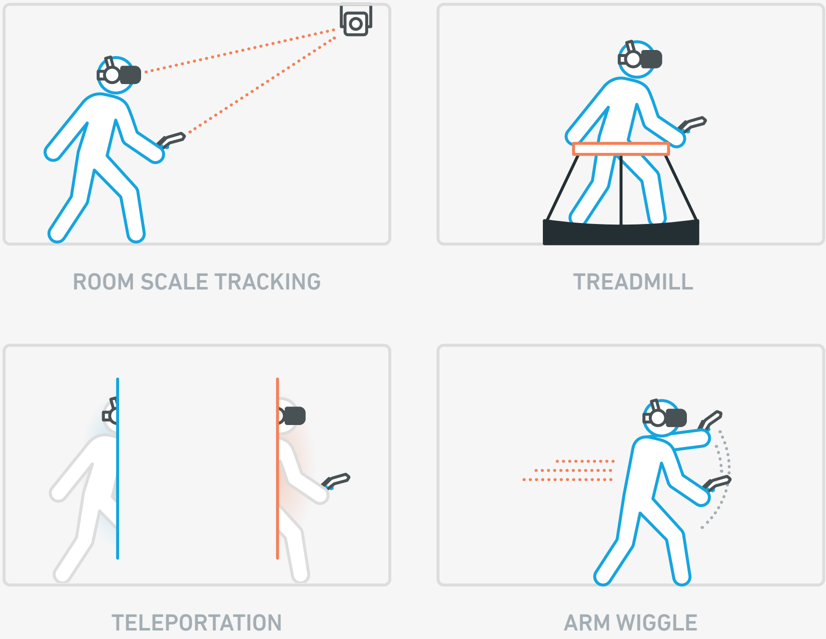
Throughout the virtual cabin, interactive props (see **Fig.63**) are placed (which can be grabbed, moved and used), facilitating potential courses of action (some of which bad or impractical):

- **Fire extinguisher:** The official way to extinguish most fires, a fire extinguisher is stored in the overhead compartments in the front. When used, it shoots a stream of Halon gas which progressively extinguishes the fires it hits. This gas stream is simulated with a particle system, where particles are shot in a conic beam with a high velocity, but slow down and divert due to air friction (limiting the range). The extinguisher is set to have enough gas for 13 seconds of continuous discharge.
- **Laptop:** A potential fire hazard with its lithium battery, several laptops are placed on the tables in the cabin. When on fire, the flames can be extinguished. However, because of the lithium battery, procedure prescribes that cooling is most important.
- **Coffee can:** Coffee cans can be used to extinguish fire (but not very effectively), but also are considered a way to cool a lithium battery. It can be used by holding it and pouring, but as this results in a narrow downwards stream this requires the user to get close to the fire source.
- **Ice can:** A can with ice cubes is available, which can be poured. However, they are not effective retardants. In the case of a lithium fire, the ice cubes actually intensify the fire as the would insulate the heat (International Air Transport Association, 2015).
- **Cooling bath:** A water bath is present in the front, which can be used to submerge a burning laptop in for cooling purposes.
- **Luggage:** Several suitcases are present in the overhead compartments, forming a potential fire hazard. They are difficult to move, and form a hidden fire source (only smoke can be seen from outside). Procedure prescribes extinguishing, then closing the overhead compartment and checking after a few moments if there is no fire.
- **Wall-mounted phone:** In the front and back of the cabin wall-mounted phones are present, which can be used to communicate to 'the cockpit' (in this case the facilitator of the simulation)

All props are simulated as physical objects, being subject to gravity and collision with other objects.

Fig.63 Interactive props in the simulation

Fig.64 Various locomotion methods for VR



Locomotion

Locomotion, moving through (virtual) space, has many available methods in VR (see **Fig.64**):

- **Room scale tracking:** Corresponding physical movement to virtual movement is likely to method that is most natural and immersive, and least prone to causing motion sickness (as felt and seen motion and balance correspond). However, the HTC Vive provides a limited tracking space (at most 5 meters diagonally), limiting freedom of movement.

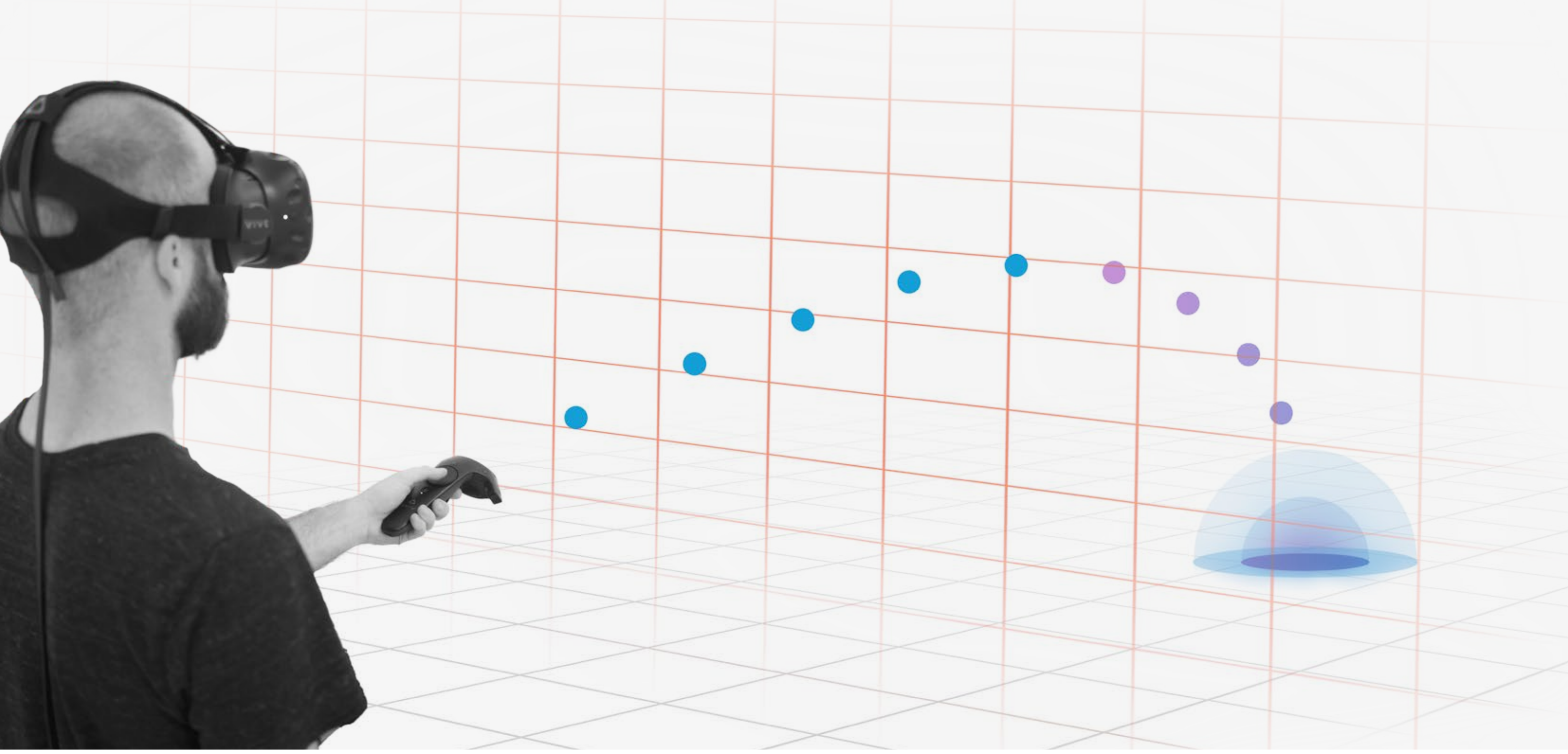
- **Treadmill:** Omni-directional treadmills for VR (e.g. Virtuix Omni) allow the user to walk whilst remaining stationary. The tracking of this movement results in limitless locomotion with a natural movement. However, there is some disconnect between intended, perceived and observed movement, increasing the likelihood of motion sickness and decreasing realism (Shanklin, 2016). Furthermore, the design of these treadmills make them restrictive for motion other than walking.

- **Teleportation:** This ability to instantly move from one place in space to another, is a popular pattern in VR. However, it may cause disorientation and has the potential to break presence (as thus far it has not been possible in real life).

- **Arm wiggle:** Many alternate locomotion methods are possible, one of which is the pattern of shaking your arms in a walking motion, which is then translated to a virtual forward motion. This would not necessarily feel like walking, but would require a similar physical effort.

Some VR experiences are designed around completely taking place within the tracked space, but this doesn't suffice for the simulation as the scale of the cabin and movement throughout during the scenario may be relevant factors. As such, room scale tracking was combined with a teleportation functionality.

Fig.65 Impression of teleportation and chaperone mechanisms



Implementation

The room scale tracking maps physical movement (position and rotation) of the HMD and controllers one to one to the virtual movement (in a virtual space of the same size). The available space is calibrated the Vive's software, which is used to identify where the floor should be, and to prevent users from bumping into walls with the Chaperone system (a virtual fence or camera overlay that shows when the user nears a wall (Volpe, 2016)).

The teleportation system extends the range of locomotion by allowing the user to point using the controllers to a location on the floor to teleport to (see **Fig.65**). This teleportation effectively moves the location of the virtual tracked space to the indicated location. While an effective and simple solution, it has some negative side-effects which became apparent during the research pilot. For one, it partially removes the reason to physically move, as teleportation is faster. Furthermore, users claimed the instantaneous movement broke the immersion (which was partially resolved by animating to the indicated position rather than teleporting instantly). Lastly, to most it felt counterintuitive to in some cases not be able to walk physically forward, but to be able to teleport forward.

While not a perfect solution, this implementation was most practical for initial prototyping.

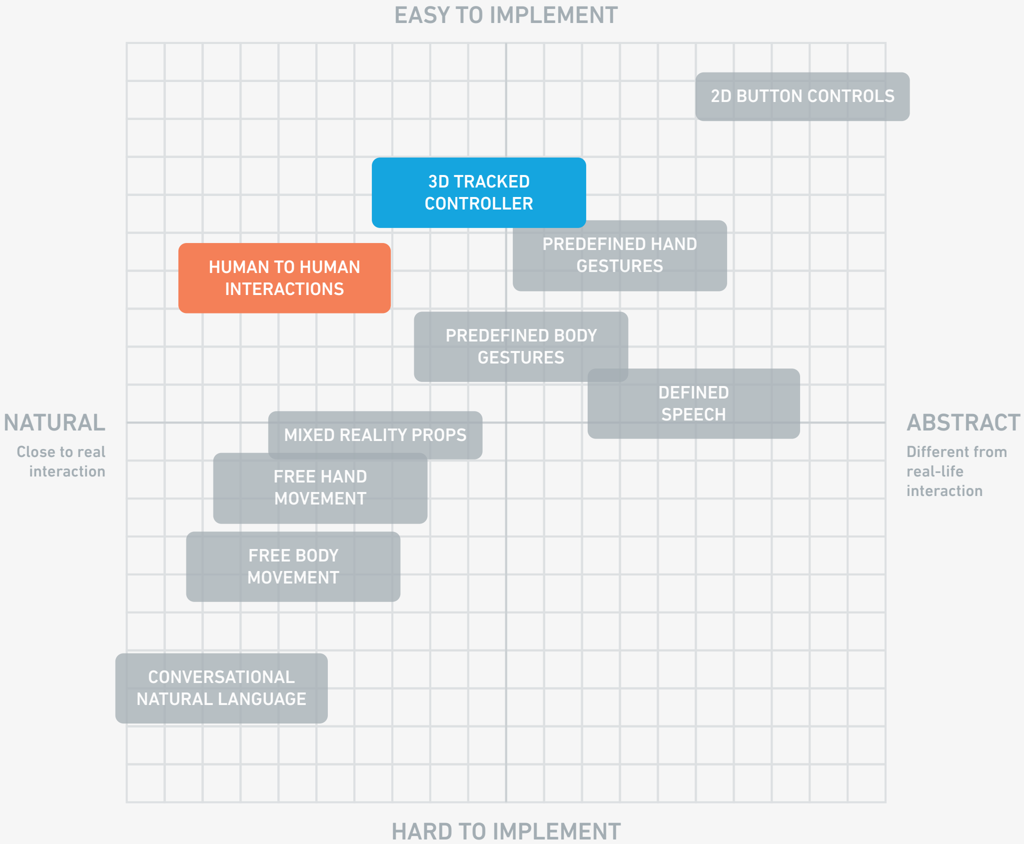


Fig.66 Interaction paradigms and technologies, in terms of ease of implementation and level of abstraction.

Interaction & controls

The interaction design in the virtual environment has to be intuitive (small learning curve) and immersive (close to reality by incorporating, for instance, physical movement). It needs to incorporate the following functionalities for direct interactions:

- Grabbing and moving of objects
- Using objects (overhead compartment, fire extinguisher)
- Teleportation
- Communication between participant and trainer

Paradigm

Fig.66 displays the interactions evaluated in the 'Simulation Technologies' section in a matrix putting ease of implementation against level of abstraction from reality. Some approaches and paradigms are very close to real as interaction models (e.g. free body movement and conversational natural language), but hard to implement, while others are simple to implement but far away from the real-life equivalent (inter)action (e.g. 2D buttons without a 3D position, or predefined voice commands).

Using a 3D tracked controller (like the ones included with the HTC Vive) allows interactions with natural movement, but is easy to implement given the availability, precision and stability of the system, as well as the unambiguous nature of a button control (the state of a button is easy to observe with high certainty). Using hand or body motion directly as input would significantly increase the chance of error.

Reliable implementation of realistic social interactions would almost certainly require contact between real humans (i.e. participant to participant, participant to instructor or participant to role-player). The one way this is facilitated in the prototype is through a virtual intercom system, allowing the instructor to talk to the participant by holding a button and speaking into a microphone.

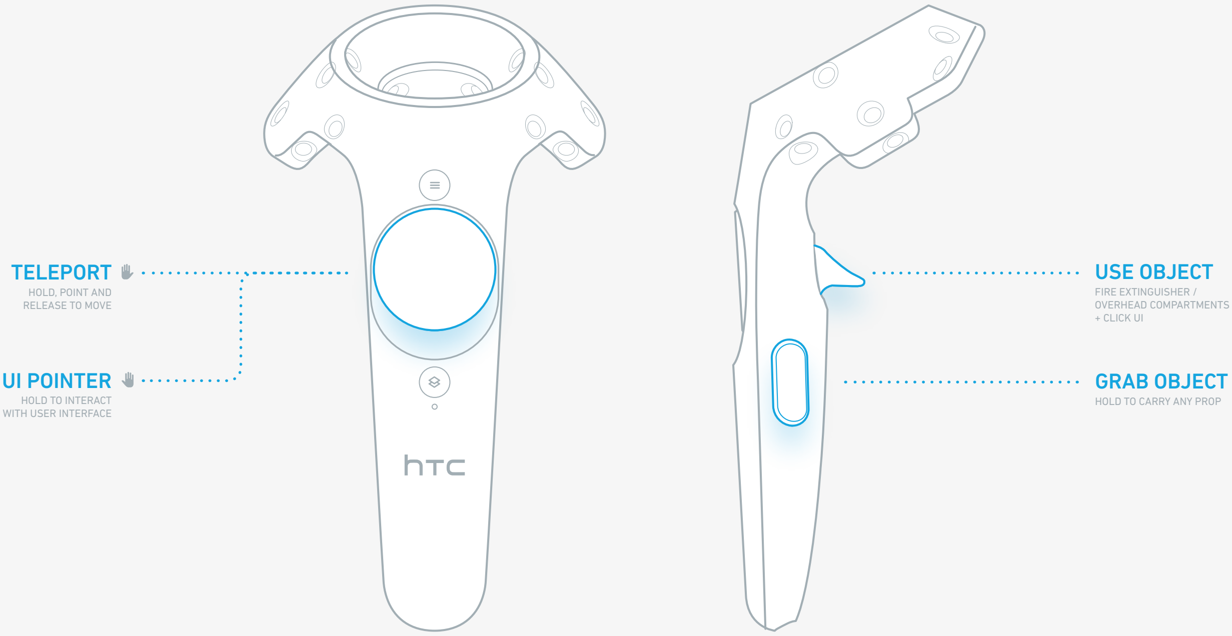


Fig.67 Initially implemented configuration of the HTC Vive controllers.

Fig.68 Grabbing interaction binds a virtual object at a preset location

Implementation

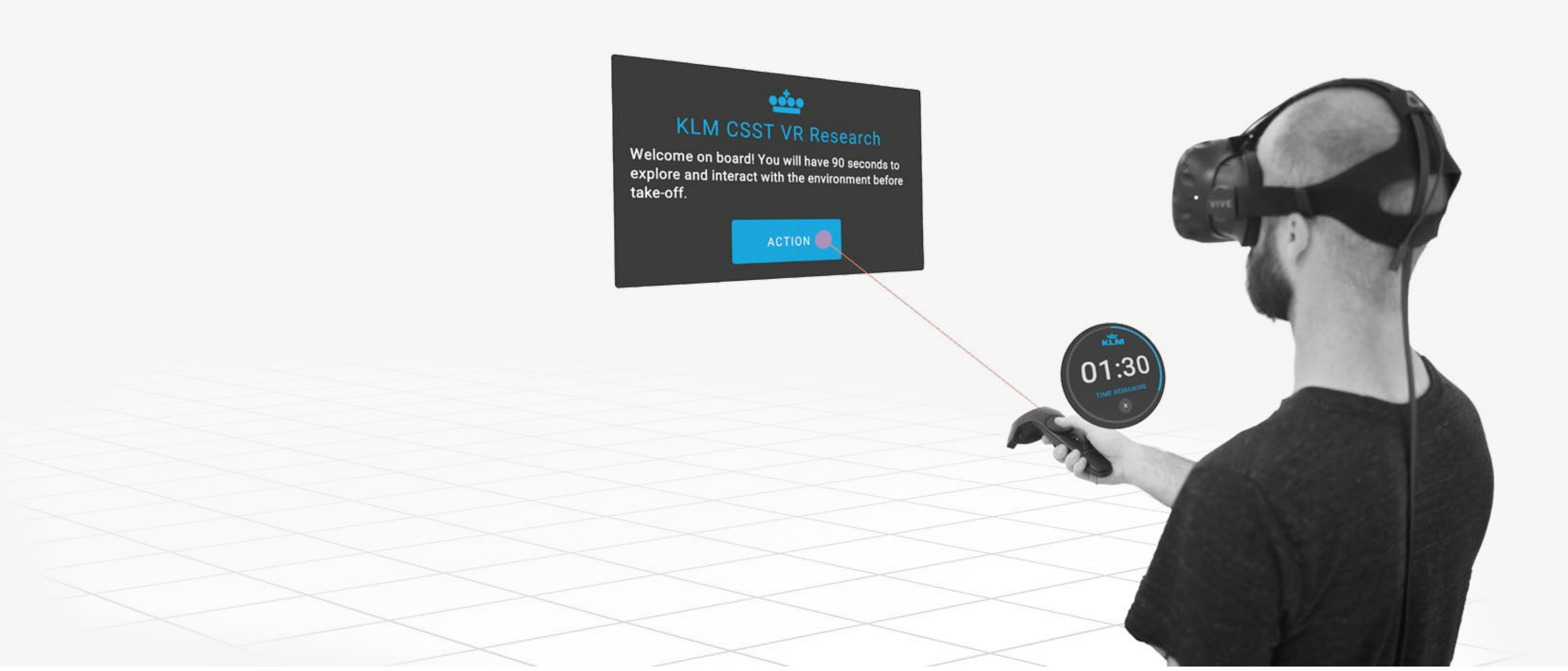
The implemented use of the controllers is displayed in **Fig.67**, with the following reasoning:

- **Grabbing objects:** to approximate the sense of holding on to something, the grip buttons on the sides were used. An object can be grabbed (see **Fig.68**) by entering it with the controller (upon which it will be highlighted), and holding the buttons. Upon release, the object falls to the ground. Several props have been configured to enforce being held in a specific manner (e.g. the handle of the fire extinguisher).

- **Using objects:** the trigger button provides a linear input, and is oriented similarly to the trigger of the fire extinguisher. As such it is suitable for simulating its use. Similarly it is used to open overhead compartments, as it emulates the motion of the handle.

- **Teleportation / UI pointer:** Both the teleportation and interaction with the text dialogues require use a pointer system, which are mapped to the remaining top button of the left and right controller respectively.

Fig.69 Dialog popup in primary position, countdown timer in secondary position and UI interaction with pointer



While several iterations went into this configuration, during the pilot and research it became apparent that these controls were not completely intuitive, and required some practice. The grip buttons are unergonomic for some, while the difference between the left and right controllers caused confusion. As such the configuration was revised in the final design (see 'final simulator design').

Scenario

While ideally the simulation can run a wide variety of custom scenarios, for the purposes of the research a single scenario was implemented, comprising a sequence of events. These events were modularized so they could be easily altered, reordered and reused, and included pop-up dialogs, countdown timers and the initiation of fires (and resulting effects).

The research scenario starts with a welcome message and an instruction to explore and interact in the virtual space (see **Fig.69**). As this dialog requires confirmation, it floats directly in front of the user (the primary UI position). Upon dismissing this dialog a countdown timer is set to 90 seconds (see **Fig.69**), which is an acclimatization period (see research method). The timer switches from the primary to a secondary position, where it floats around the wrist of the user (similar to a watch). This is done as the information shouldn't obstruct the user's view, but be available on demand.

After acclimatization, three random objects (with the property that they can combust), are set on fire. Different objects have different ways of burning (see **Fig.70**). For instance, a laptop will have a burning lithium battery, which requires specific procedures. As the user gets the opportunity to deal with the situation (extinguishing, cooling, calling the cockpit, etc.), a timer for 5 minutes floats in the secondary position.

Audio and effects

Both auditory and visual effects are added in an effort to increase immersion, particularly during the emergency scenario.

For each fire, both flames and smoke are simulated using a particle system. The amount of smoke and size of the fire depend on size and type of the source of the fire, as well as the intensity. Furthermore, as long as the fires persist, the cabin will increasingly become filled with smoke, to the point that it obscures the view. This is done using a large separate particle system with large, semi-transparent particles that persist longer and move more slowly, as this is much simpler than to actually simulate how all smoke from the fires would move through the cabin over time.

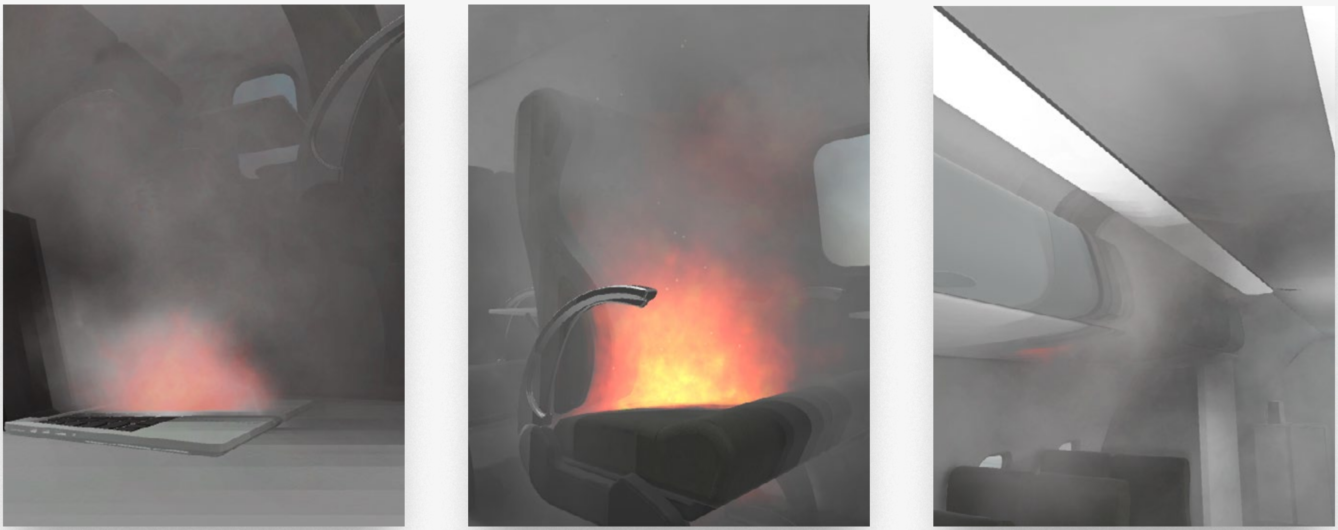


Fig.70 Different fire / smoke particle effects for lithium fire, open fire and hidden fire respectively.

Audio

Audio is an extremely important aspect of creating immersion (Brinkman et al., 2015), but it has to be dynamically generated to adapt to the situation. Furthermore, to connect the sounds to the space, it is possible to give the sources of sounds a position in the virtual space (resulting in a volume and directionality depending on the users position and orientation). The simulation includes the following audio layers:

- **Engine / crowd noise:** Several looping recordings of aircraft noise and a longer recording of passengers are layered to serve as a 'white noise' of sorts for the aircraft context. These sounds are largely non-spatialized, as one would hear them anywhere throughout the aircraft.

- **Announcements:** The intercom system is spatialized, but set to spread sound through the cabin, as typically there would be multiple speaker systems playing the sounds. It plays both pre recorded announcements from a pilot and the spoken instructions from the facilitator. To prevent breaking immersion, the intercom plays an announcement tone prior to every announcement, and includes several audio effects to distort the voice (as is typical for intercom systems in aircrafts).

- **Alarm:** after the smoke spreads through the cabin during the fire, the alarm is triggered. This is an intense, loud sound, which plays every few seconds as long as the smoke persists. Normal fire alarms play more frequently, but rapid beeping patterns signal a command for evacuation in the aircraft context.

- **Fire:** each fire produces a fully spatialized sound, as this is in part important to assist users in locating the fire. To differentiate the fires (both for orientation and increased realism), for each the pitch and volume is slightly randomized.

- **Passenger response:** The hypothesis that a real-life fire emergency would be more stressful than the training is based in part on the idea one would likely have a panicked crowd surrounding them. A separate system was created to randomly play clips, positoned randomly throughout the space, from a set of 12 recordings, including hysterical outbursts, coughing (in response to the smoke), and panicked or crying adults and children. Several clips are played simultaneously, resulting in a sound that seems fairly varied for several minutes.

Performance vs. fidelity

Performance optimization seems like a arbitrary challenge for the end of a development cycle, but in VR it is fundamental to the quality of the experience. Recommended frame rates to prevent motion sickness and sustain immersion range from 60 (Hall, 2016) to 95 (Abrash, 2014) per second, with at most 20-25 ms latency in motion tracking (Abrash, 2014). However, there is typically a tradeoff between visual fidelity and performance. Fidelity is often not important to create presence (Lugrin et al., 2015, Poeschl et al., 2014), but ongoing research shows visual fidelity can help elicit a physiological response (e.g. stress) (The Verge, 2017). Several optimizations were made to increase visual fidelity whilst retaining high performance.

Pre-computed lighting

Rather than calculating how the interior lighting and sky light the environment (and how that light bounces around through the environment) in real-time, it was decided to calculate this in advance (baked lighting). This is possible because most objects in the environment are static, and therefore will look the same throughout the simulation. Even dynamic objects can use this lighting system, using light probes. These probes sample the light at different points throughout the space. A comparison is displayed in Fig.71. A downside of this system is that it becomes more challenging to change lighting dynamically (e.g. change to a night setting).

Simplifying and merging objects

Virtual 3D objects in games are typically polygon meshes (in essence, a collection of triangles). The amount of vertices (points) and triangles (i.e. level of detail) is a significant determinant of how complex it is to render these objects. Most objects were created in NURBS geometry (comprising mathematically defined curves rather than polygons), and thus were converted to meshes with the lowest resolution that still retained an acceptable level of detail.

Visual effects

Besides audio, visual effects can be a computationally cheap way to add to the fidelity and realism of the simulation (see Fig.71).

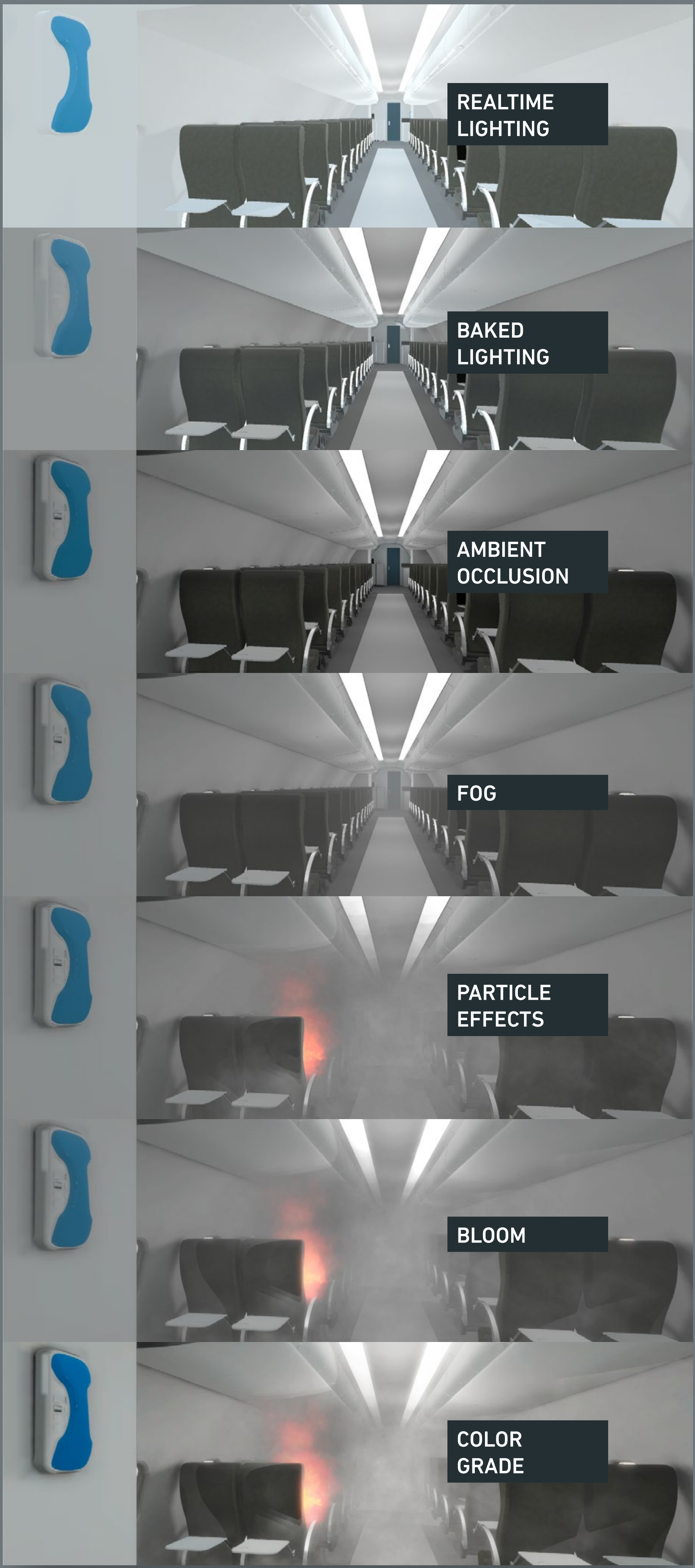
- **Ambient Occlusion:** There is typically less light in tight corners, an effect which can be emulated by artificially darkening these corners. This typically results in objects seeming more grounded on surfaces, rather than floating through space.

- **Particle Systems:** The particle effects (fire, smoke, water) seem fully 3D, but rather are collections of images of single particles (oriented towards the virtual camera) moving through 3D space with specified physics.

- **Bloom:** Due to the limited brightness of the HMD it is difficult to convey intense light. A bloom effect generates a halo around bright spots. This effect also typically reduces the seeming artificiality of the environment.

- **Color grade:** While not physically correct, the adjustment of brightness and colors can dramatically influence the mood of the environment. For the sake of realism, a rather subtle grading was done.

Fig.71 The visual impact of lighting technique, particle effects and post-processing effects



Research Setup

A USER STUDY WAS CONDUCTED, COMPARING THE FIRE FIGHTING TRAINING, AS IT'S CURRENTLY FACILITATED AT CSST, TO THE DESIGNED VR FIRE FIGHTING SIMULATOR. THE STUDY IS FULLY DOCUMENTED IN THE ATTACHED RESEARCH PAPER (APPENDIX C), AND SUMMARIZED IN THIS SECTION, WHICH WILL GO INTO ADDITIONAL DEPTH REGARDING THE DESIGN IMPLICATIONS OF THE FINDINGS.

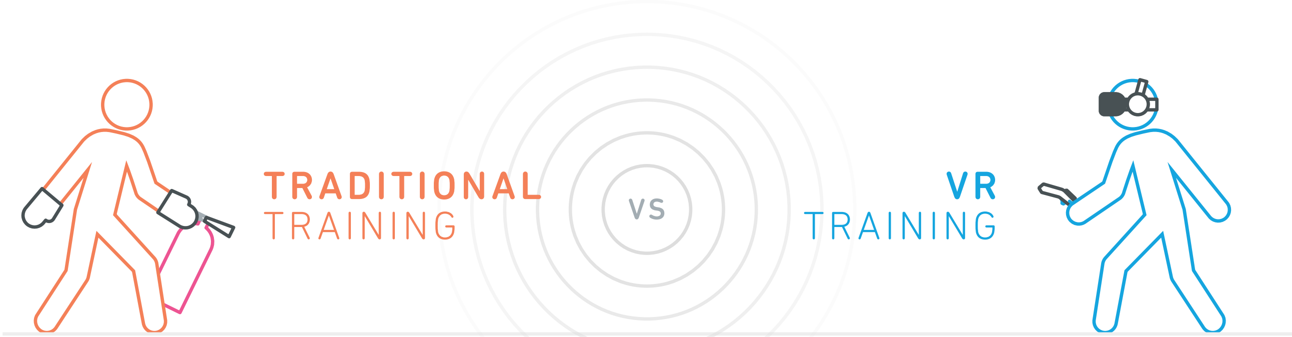



Fig.72 Physical props and interactions


Fig.76 Virtual props, Semi-physical interactions


Fig.73 Real, controlled fire in predefined locations


Fig.77 Uncontrolled fire in random locations throughout cabin


Fig.74 Equipment is fetched in advance

Fig.78 Diverse props placed throughout space


Fig.75 Smoke as indicator for fire source


Fig.79 Obscuring smoke spreading throughout cabin

Simulation Exercises

Both simulation exercises the participants are subjected to are modeled after the in cabin fire fighting training at CSST, in which multiple fires occur at different locations throughout the modeled section of the cabin and three trainees are asked to divide tasks (A, B & C roles) and follow prescribed procedures to deal with the situation (searching source, extinguishing the fire, communicating to cockpit, etc.).

The only sense in which the 'traditional' exercise in the study differs from regular training is that there is only one concurrent participant, taking the A role (dealing with fire and communicating the situation to B). The present instructor is free to facilitate the training as he/she would in regular training, which typically has a conversational style and in some cases features instructional elements.

The VR exercise was developed for the research to allow participants to follow the vast majority of thought procedures, but adds several elements in an effort to more closely represent a real-world cabin fire emergency: a full-scale interactive cabin, contextual audio (panicking crowd, smoke alarm, cockpit announcements, engine noise) and smoke effects. Furthermore the VR simulation enables multiple courses of action, thus incorporating a degree of decision making. Participants can physically move throughout the virtual space (locomotion and interaction), as the simulation uses room-scale VR system (HTC Vive).

Measurements & analysis

Besides the general response to a VR training, three topics are of interest: presence, stress and performance (see **Fig.80**). Each has its own metrics.

Each participant was subjected to both exercises consecutively, in alternating order to counteract potential learning effects. During each exercise the following were recorded:

- **Heart rate:** Changes in heart rate are indicative of arousal or physical activity. While blood pressure is a better indicator of stress (Dimov, 2017), it can only be measured whilst seated. Heart rate, in particular its variability, can be indicative of stress when combined with other metrics.

- **Video:** videos (including screen captures of the VR simulation) were recorded to later be analyzed by a CSST instructor, serving as the basis for the performance

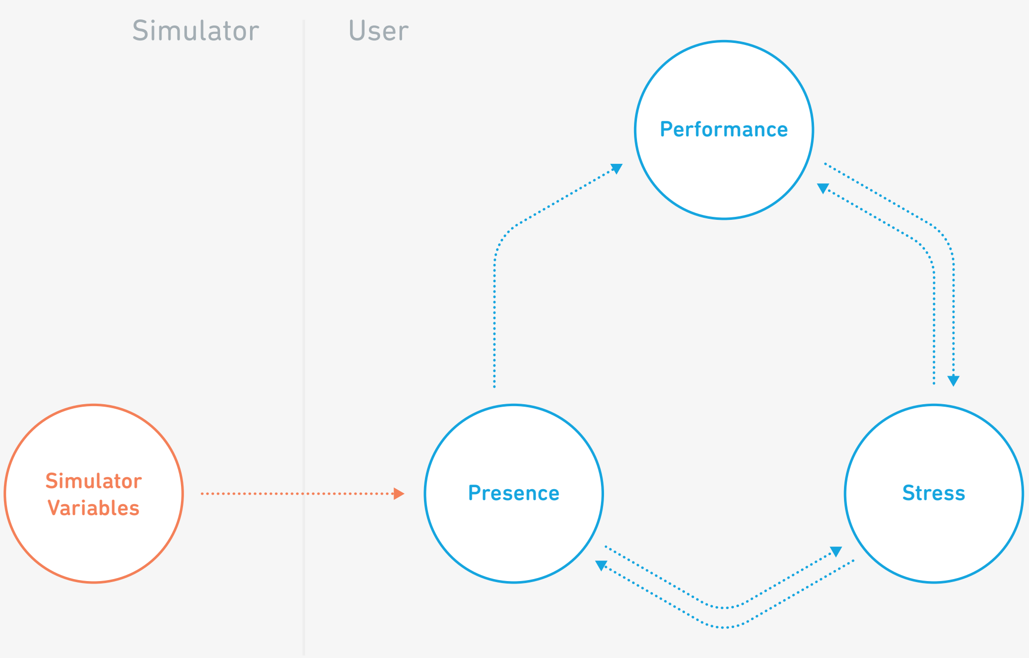


Fig.80 Variables and relations of interest in the study

metric. The criteria (see appendix C) for the performance assessment were formulated in a way to overcome the differences between the exercises and avoided strict definitions of right and wrong behaviour,as this is contextually dependent.

After each exercise a questionnaire (see appendix C) was administered, including:

- **NASA Task Load Index**: The TLX (Hart, 1988) is a common way of measuring task load, which includes indicators for both stress and perceived performance
- **ARI questionnaire** (Georgiou, Y., & Kyza, E. A., 2017): This proposed questionnaire is on immersion in AR. However, some questions specifically concern presence and are more broadly applicable. In addition to several open questions concerning what makes and breaks immersion, this questionnaire is seen as indicative of to what extent they experienced the simulation and their role in it as real.
- **General questions:** Age, experience as CA, experience with fire fighting, general feedback.

The test procedure (see **Fig.81**) is initiated with an introduction and instruction to the participant what is expected from them. Each simulation round is initiated with 90 seconds of acclimatization to the simulated environment (the fire room and the vr aircraft cabin respectively). This is done in part to create a baseline of the heart rate of each participant whilst standing, without any task or emergency. In the case of the VR exercise, the participant is given the opportunity to become acquainted with the controls and interaction paradigms (including verbal instructions).

Participants

After a trial with TU Delft students, the study was conducted with 7 KLM cabin attendants (CAs), of whom two were in the process of transferring from a different airline and four had no prior experience (as they were in initial training). With an average age of 30, most participants are significantly younger than the average KLM CA. However, this group was sought out intentionally to observe potential effects of long-term experience with fire fighting procedures.

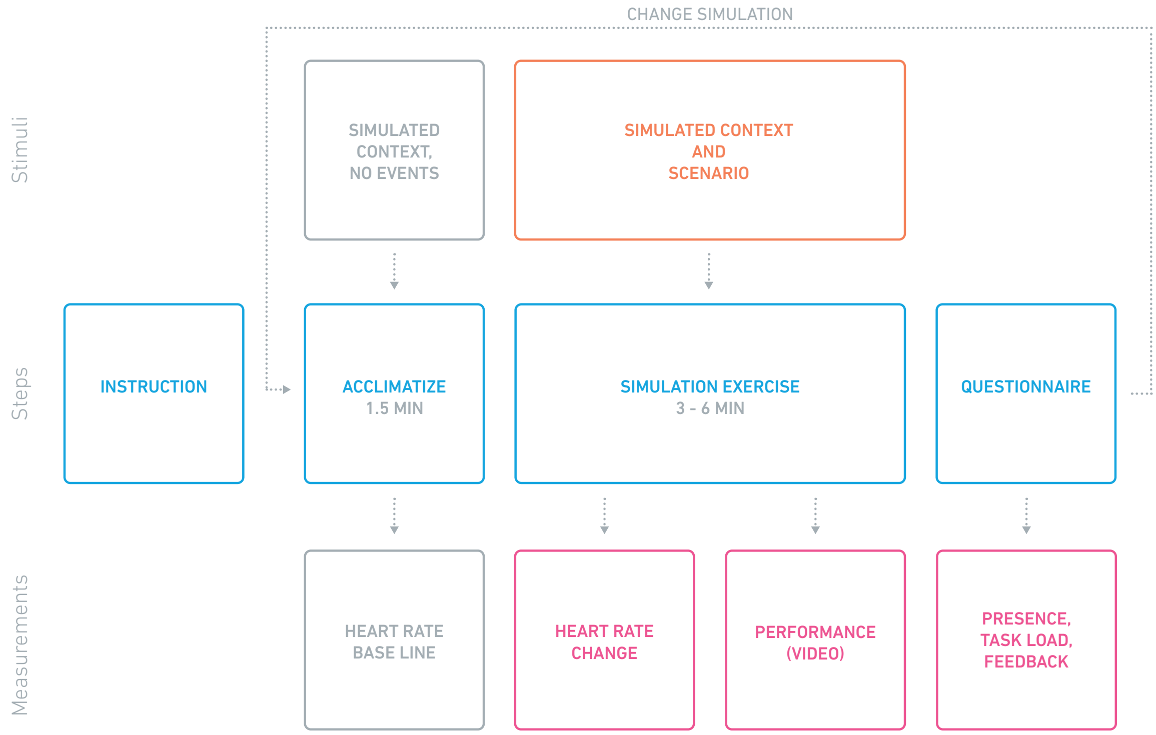


Fig.81 Test procedure for individual participants

Results and observations

AFTER CONDUCTING THE STUDY, THE DATA WAS PROCESSED AND ANALYZED IN COMBINATION WITH GENERAL OBSERVATIONS AND FEEDBACK. CONNECTIONS AND PATTERNS WERE SOUGHT OUT USING PEARSON CORRELATION AND REPEATED MEASURES ANOVA (THE EXACT RESULTS OF WHICH CAN BE FOUND IN THE RESEARCH PAPER)

Heart Rate

On average, the heart rate of participants was higher in VR than in the traditional exercise during the simulated emergencies, whilst being practically the same during acclimatization (see **Fig.82**). The VR averages peak 10 to 15 bpm higher. In both exercises, heart rate typically rises as the emergencies occur, but slowly falls afterwards.

Between participants heart rates differ greatly, particularly in VR (SD=23.5), with some able to sustain a fairly consistent, low rate while others show large fluctuations.

Additionally, it has to be noted that wristband based heart rate monitors (like the one used) are prone to noise and subsequent inaccuracy, particularly whilst moving (due to changing light conditions) (Binsch et al., 2016). This makes it impossible to correlate specific peaks in the heart rates of individuals to events in the simulation.

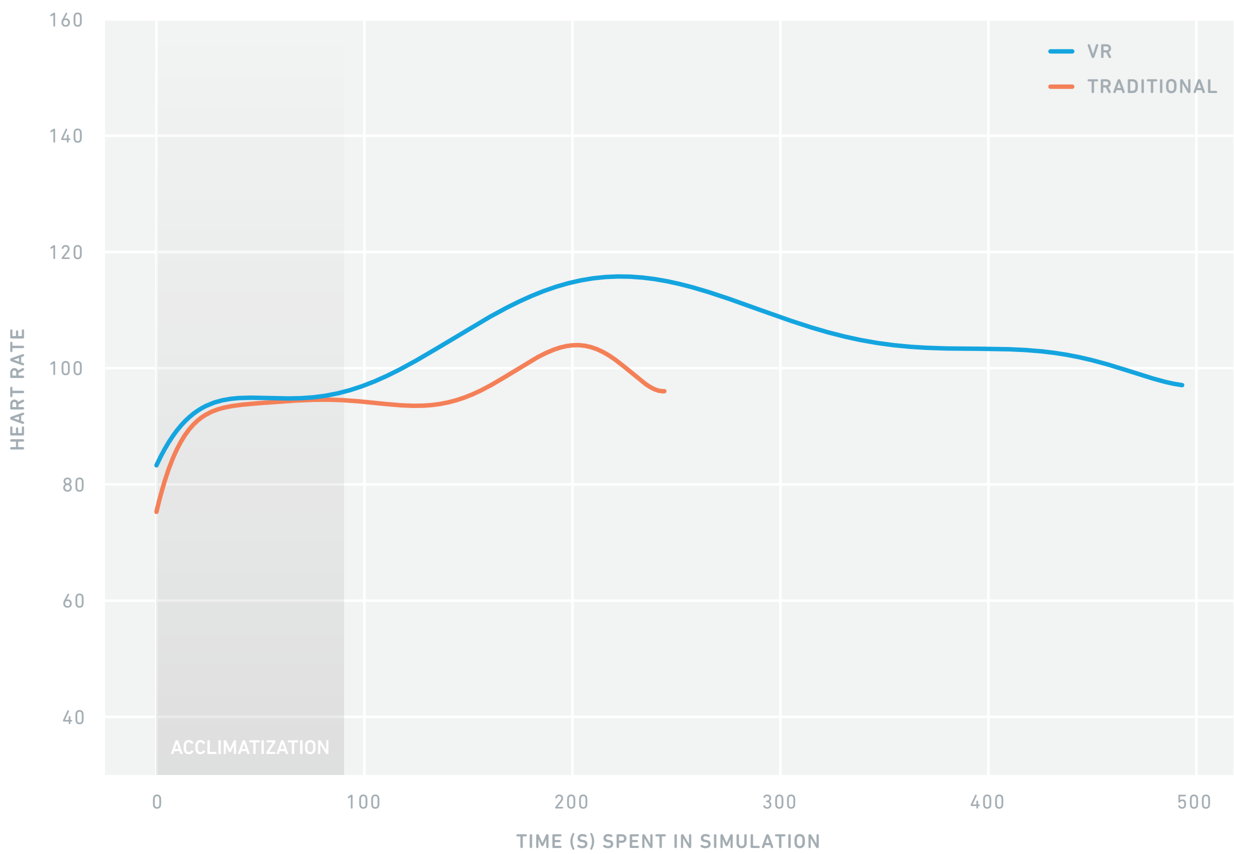


Fig.82 Average heart rate of participants over the duration of the exercise

Task load

Participants found the VR exercise more challenging in every aspect, except physically, with average task load of 3.86 (VR) and 2.69 (traditional) respectively. In particularly, they thought it was more frustrating, stressful and mentally challenging.

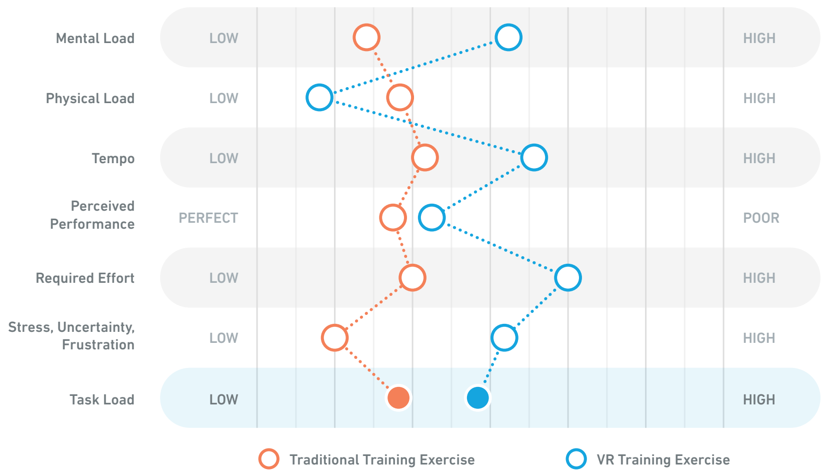


Fig.83 Average task load score on Likert scales for traditional and VR exercise (n=7)

Performance

Participants performed somewhat worse in VR, in particular due to poor communication and a higher amount of made mistakes. They frequently forgot or ignored both instructions and procedures while in VR, resulting in disorientation and in some cases inability to deal with the emergency.

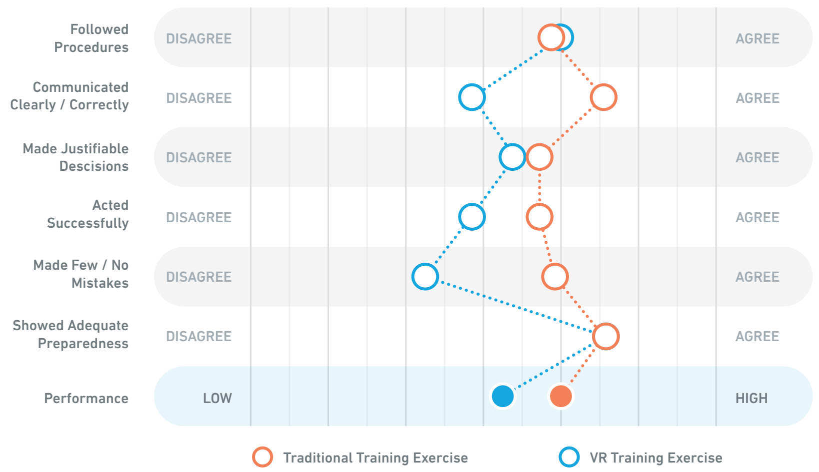


Fig.84 Average performance rating by instructor on Likert scales for traditional and VR exercise (n=7)

Presence

No significant difference in the average presence scores in the the exercise was found, while they did differ in some of the aspects the score comprised. VR is seen as less fictional and more interactive, but the participants felt less in control and able to act.

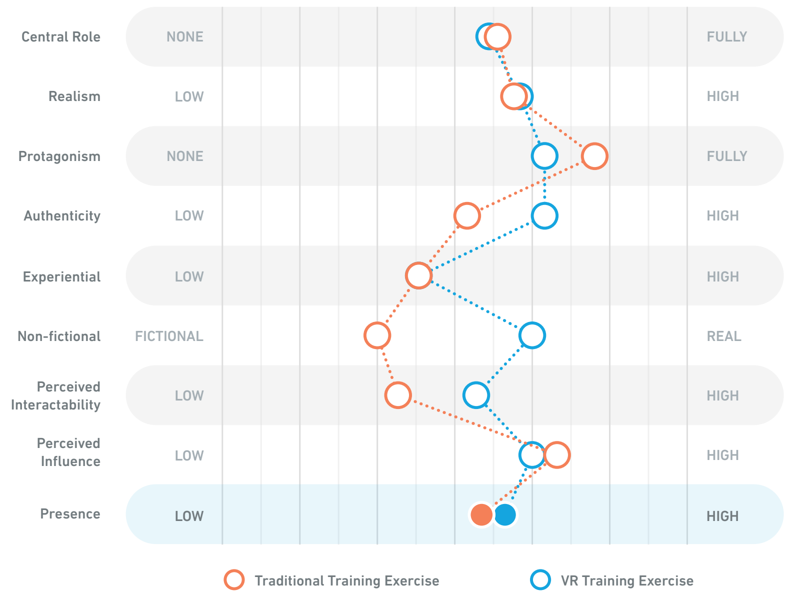


Fig.85 Average presence rating on Likert scales for traditional and VR exercise (n=7)

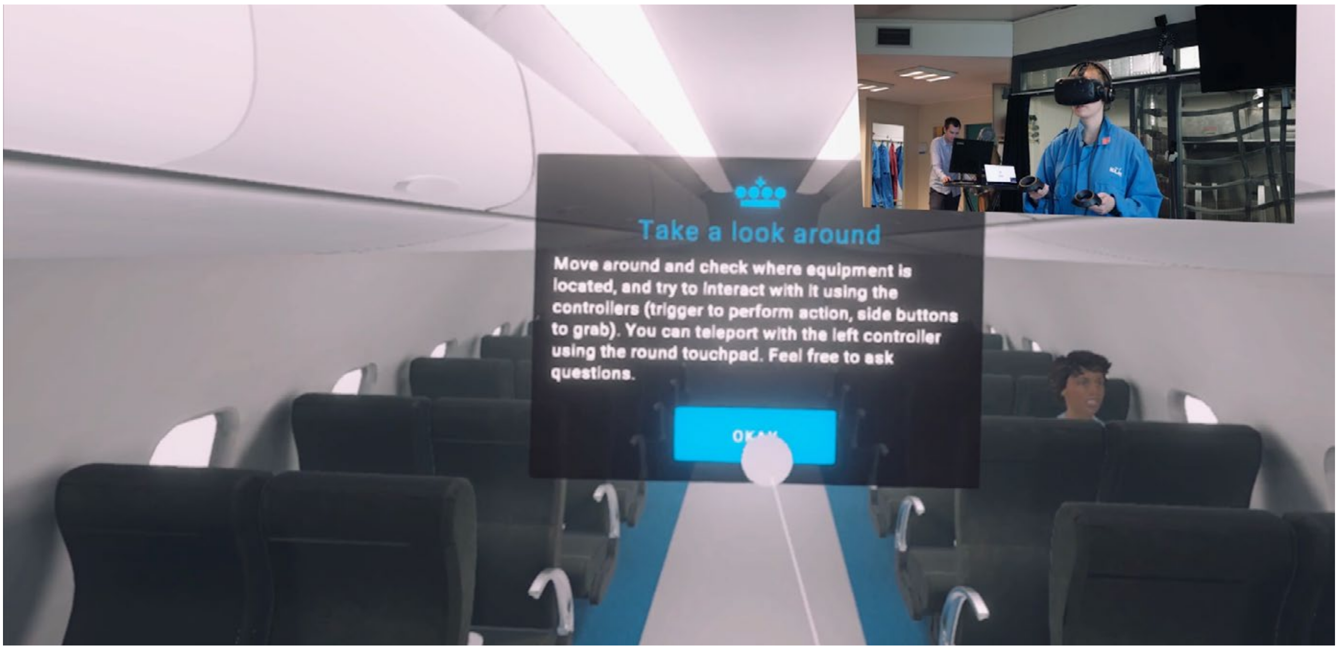


Fig.86 Participant dismissing the instruction dialog at the start of the test (Video overlay on screen capture).

Fig.87 Participant after fetching the fire extinguisher (Sceen capture with overlay from video)

Relations between stress, presence and performance

Given the small sample, the potential for significant correlations was limited. However, several patterns are interesting, both for further research and design consideration:

- Heart rate shows a positive correlation to task-load, in particular to the stress / frustration aspect (significantly so).
- A positive correlation may be present between presence and task load, but no connection between presence and heart rate apparent.
- Strong positive correlations are present between presence and the perceived tempo and required effort of the exercise.

Wow, that was so bizarre

It is a really cool experience! I started sweating, or did you put on the heater by any chance? In any case, it was really exciting.

That you actually extinguish the fire, and the real smoke [add to immersion]. Personally I would increase the available space [...] because now I continuously walked into the walls.

I was more occupied with figuring out how to use the VR controls than actually extinguishing the fire

I would place equipment in the same place as an actual aircraft. And for instance show how the passengers respond.

I would like more clarity what exactly my task is.

Fig.88 Quotes from participants on the VR simulation

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 over-looking 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, or the inconsistencies of the simulated context and the actual aircraft interiors they have been familiarized with. An example of the latter is how the alarm sound in VR caused several participants to look for a toilet (as its alarm is the one most commonly triggered in aircrafts), but there was no toilet part of the simulation.

In VR, participants noted that the simulated environment, smoke and sound contributed to the sense of immersion, while the teleportation functionality (for moving more than a few meters) detracted from it. Interestingly, while the exercise was seen as more authentic, participants felt that their actions were less representative of reality than their actions in the traditional exercise.

In the traditional exercise, participants felt that the physical props and interactions contributed to their immersion and resulted in an ability to effectively practice their procedure skills. However, the abundance of space and lack of simulated context made most less immersed. Three thought that the scenario would pan out differently in reality.

Conclusions and implications

> THE VR EXERCISE SHOWED SIGNIFICANTLY HIGHER TASK LOAD AND SOMEWHAT LOWERED PERFORMANCE, NO SIGNIFICANT CHANGE IN PRESENCE AND HIGHER AVERAGE AND PEAK HEART RATES.

The latter, particularly when combined with the lower reported required physical effort, points to increased arousal. In line with the heightened reported stress / frustration and the apparent tunneling, this is a somewhat strong indicator of increased stress levels in the VR exercise, compared to the traditional exercise.

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 general notion that the VR simulation was less fictional and more authentic seems somewhat contradictory to the participants claiming that their performance in the traditional exercise was more representative of how they would act in reality. This can point to one or a combination of three things:

- Participants think the larger context of a real-world emergency wouldn't impact their ability to follow procedures (or their validity).
- Participants would actually respond poorly to the contextual pressure and unpredictability, but this is not exposed in training
- The VR exercise was able to convincingly simulate context, but lacked in the refinement of its interactions, and the platform's novelty itself formed a challenge.

Similarly, a frequent complaint about the VR exercise was the comparatively small amount of instructions. This indicates a reliance on being led and instructed throughout the exercise (as is typically done in the traditional exercise, but which likely won't be in real-life emergencies). Combined with the worse performance and heightened task load in VR, this actually makes a case for the necessity of such a training: CAs should be somewhat able to act decisively and responsibly in unfamiliar situations.

Design Impact

The following take-aways are significant for the further design and development of the simulation:

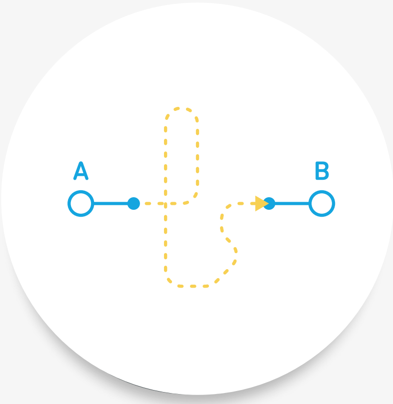
- **Hard skills vs. professional judgment:** It seems unlikely that the VR simulation can be an effective and law compliant way at training for hard skills (e.g. using a fire extinguisher, following a fixed set of steps). The study's results were discussed with Olaf Binsch (TNO) (see Appendix B), who has done similar research on VR in military context. According to him, drill-based training is effective at ensuring personnel can follow pre-defined tasks under pressure. However, it does not prepare for when a situation requires higher level decision making. This reinforces the notion that the VR training should be focused professional decision making in high pressure situations (i.e. unexpected situations with uncertain progression and high-stakes outcome).
- **Training is collaborative:** both traditional training and real-world scenarios are of a collaborative nature: CAs are not alone in how they act, and don't have to think about all things at once. The VR simulation should in some way facilitate collaboration or a strict boundary of responsibilities.
- **VR is not immediately intuitive:** During a regular training day, there is little time per participant for on-boarding a simulation. The controls and interactions in the VR exercise caused initial confusion as they are contextually dependent and differ slightly between the controllers. Can this be simplified, or can a more efficient on-boarding be designed?

5 | DESIGN

Fig.89 KLM employee in uniform wearing HTC Vive HMD, holding controllers.

Design Goals

BESIDES, THE SIMULATION ITSELF, WHAT TOPICS NEED TO BE ASSESSED TO CREATE A SUCCESSFULLY INTEGRATABLE DESIGN PROPOSAL?



User journey

What activities of instructors and trainees does the use of the simulator in the training constitute (including instructions, on-boarding and off-boarding)?

Infrastructure

What sort of space, hardware and system level connections does the design need to function and integrate?

Observe and evaluate

How can the participants' performance be recorded, observed and evaluated to improve the learnings?

Collaboration

How can the simulation facilitate collaboration between participants, and incorporate the social aspects of training?

Simulation control

How can trainers / students control the simulation, create specific scenarios, in order to tailor the learning experience for personal relevance.

Communication

How should information, such as events, possible courses of action, tasks and contextual hints, be presented, in an engaging, understandable and challenging way?

Approach & Criteria

THERE ARE MANY VARIABLES TO CONSIDER BEFORE A COHERENT AND INTEGRATED DESIGN CAN BE PROPOSED. THIS CHAPTER DEFINES THE APPROACH, AND A SET OF GENERAL CRITERIA.

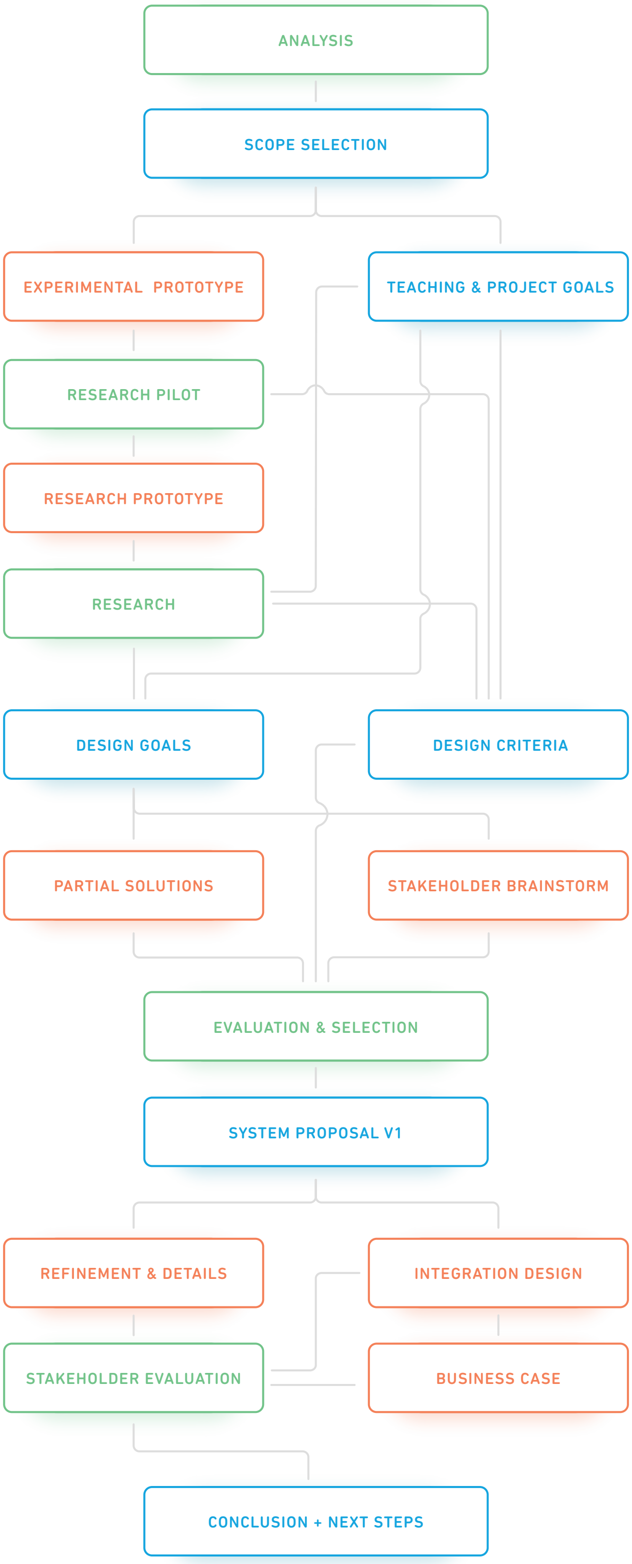


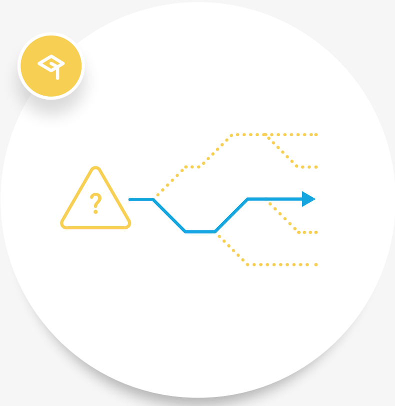
Fig.90 Schematic overview of design process

The design process is visualized in **Fig.90**. As VR is a technology that speaks to the imagination, but really has to be experienced to understand the potential and pitfalls, a research-driven design approach was taken for the core simulation: after selecting a scope for the research, iterative and experimental prototyping and user validation in both the research pilot and research gave a wide range of insights into how people behave in VR, how interactions should work and information should be presented. Additionally, it sparked the imagination of its users. Combined with the defined learning goals and project goals, this yielded a notion of what aspects a design proposal should entail to be successful in the CSST context.

The different design goals are ideated upon in individual synthesis of partial solutions and brainstorms and conversations with stakeholders (particularly in relation to the user journey). The generated Ideas are evaluated according to the set criteria, and combined into a first version of the design proposal, which is subsequently presented and discussed. While the design is refined, detailed an integration plan and business case are drawn up. This full proposal is then evaluated with the different stakeholders (trainers in particular). Based on the findings from this validation, conclusions on the design proposal are drawn and a checklist of recommended next steps towards implementation is formulated.

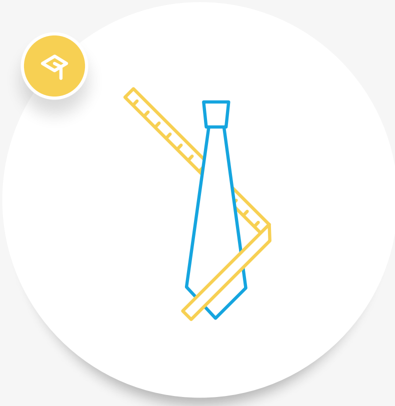
Criteria

The following is a set of criteria by which each partial solution and aspect of the design proposal will be evaluated (when applicable). Furthermore, each design topic (simulation design, system architecture, user journey, system architecture) has a set of topic specific criteria and requirements. A non-exhaustive list of requirements to which the final design has to comply can be found in appendix D.



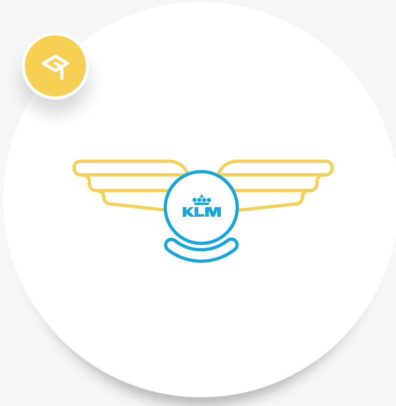
Professional Decision Making

Does the solution train and require a degree of professional decision making reminiscent of that required by unpredictable critical situations?



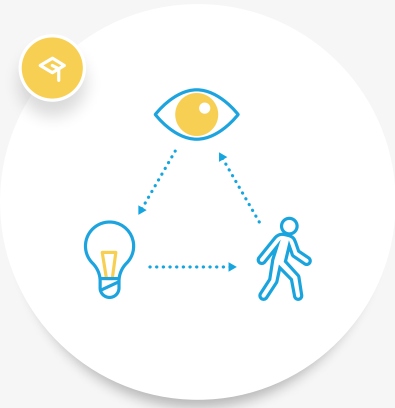
Tailored Learnings

Does the solution enable more personally relevant training with higher versatility and specificity?



Professional Attitude

Does the solution improve understanding and attitude towards safety and security on the job?

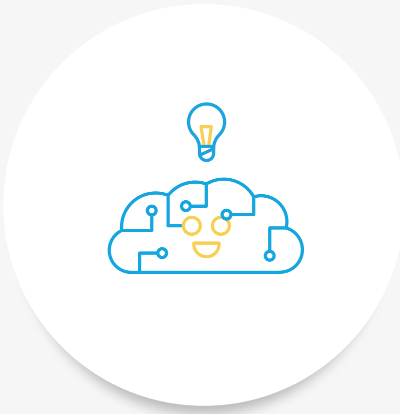


Performance Evaluation

Is the solution a valuable and practical means of yielding learnings through reflection and evaluation?

Feasibility & Costs

How feasible is a stable implementation of this solution technically, practically and financially in the short term?



Ease of Use

Can this solution be used easily by its users, with limited to no prior knowledge? Or, is the amount of required training acceptable given the benefits it yields?

User Journey

TO START USING THE VR SIMULATION, IT HAS TO BECOME AN INTEGRATED PART OF TRAINING ACTIVITIES. AS SUCH, USER JOURNEY AND THE CONNECTION TO THESE OTHER ACTIVITIES (E.G. THEORY TEACHING) NEED TO BE CONSIDERED TO DEFINE HOW THE PROPOSED DESIGN AND SURROUNDING SYSTEM WILL FUNCTION.

Additional criteria

In addition to the general criteria, the following aspects are import to the user journey:

- **Time efficacy:** training days are unpaid, take CAs out of circulation and are crammed with activities. As such, the training needs to make a swift but significant impact in order to be valuable.
- **Availability:** A concern at CSST is that actionable knowledge of CAs drops during the half year between recurrent training days (see **Fig.91**). Increased ability to practice or engage with the content of the training throughout the year would, theoretically, allow for a more stable amount of sustained knowledge.
- **Flexibility:** While this section sketches a view of a potential user journey, its elements shouldn't be too prescriptive of how they are used, but rather empower CSST (and its trainers) in facilitating the most relevant training.

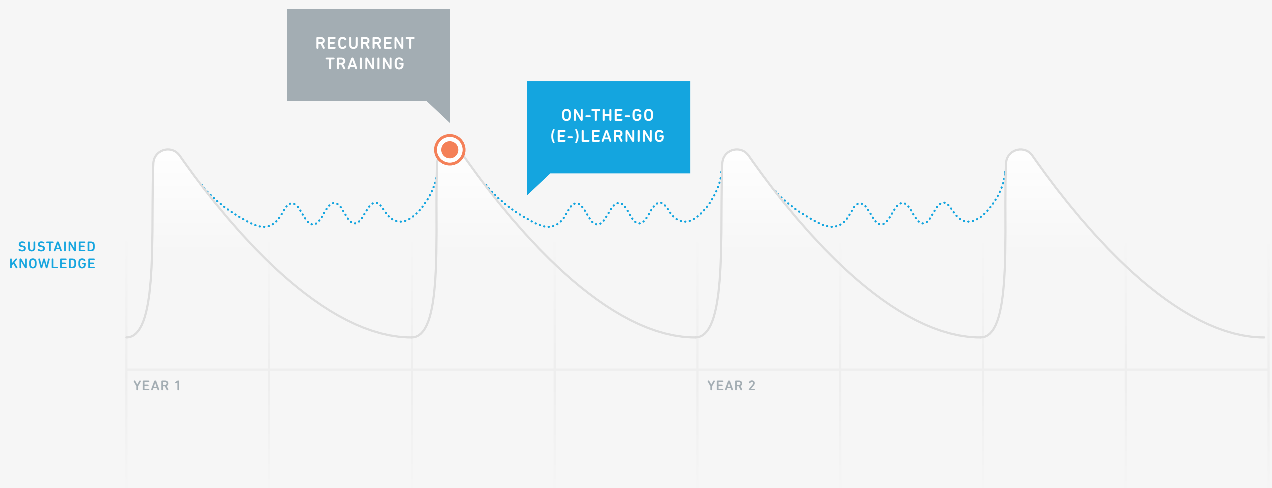


Fig.91 CSST's E-Learning strategy for sustained knowledge throughout the year

Context

Training and practice could take place at several locations: the CSST facilities, selected airports (practice while waiting), hotel rooms or at home. While, with recent developments in inside-out tracking of surroundings (Microsoft Hololens, Google Daydream WorldSense (see **Fig.93**), Apple ARKit, etc.), it has become possible to create a room scale VR experience anywhere without prior setup, there is still a clear trade-off between the achievable quality of the simulation and its availability (see **Fig.92**).

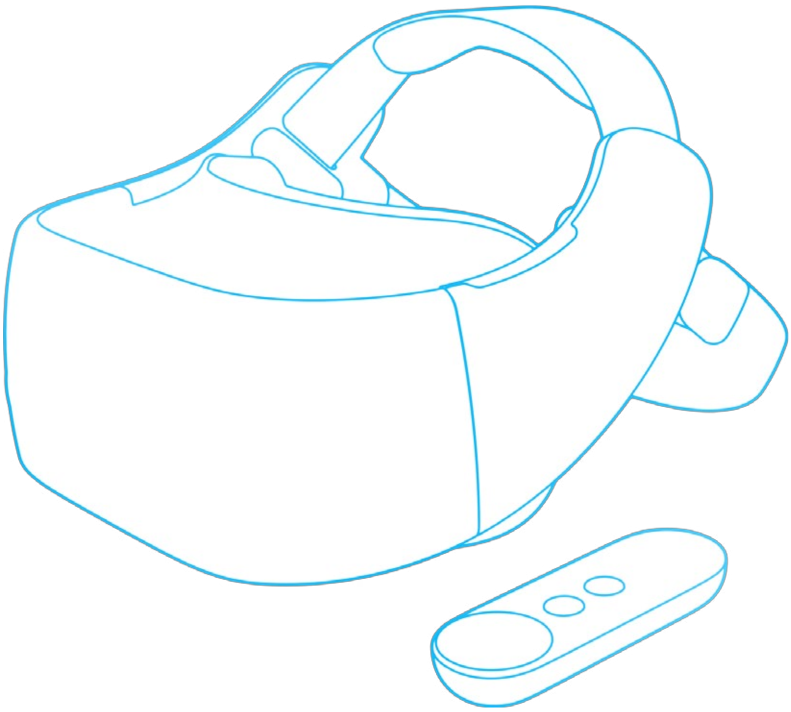


Fig.93 Form factor of standalone VR system with inside-out tracking (WorldSense), to be released by HTC in late 2017 (Google, 2017).

On the one hand, keeping training at the CSST department allows KLM to build high-end VR experiences, but at the cost of availability. Alternatively, a standalone system (i.e. headset with controller(s)) would create a high availability of medium fidelity simulation, by extension helping to sustain knowledge throughout the year. However, that would decrease opportunity for collaborative training, professional support and feedback (although it could be done remotely). The middle road is to install high fidelity VR systems at selected airports, allowing groups of CAs to practice together (and peer-evaluate) whilst waiting.

All options have their application, and should be considered for long-term application. Especially mini training facilities at airports have potential and could be rented to other airlines. However, for short term feasibility of integration and to support the performance evaluation learning goal, the user journey will primarily take place within the CSST facilities. However, ways of extending parts to the other contexts are considered.

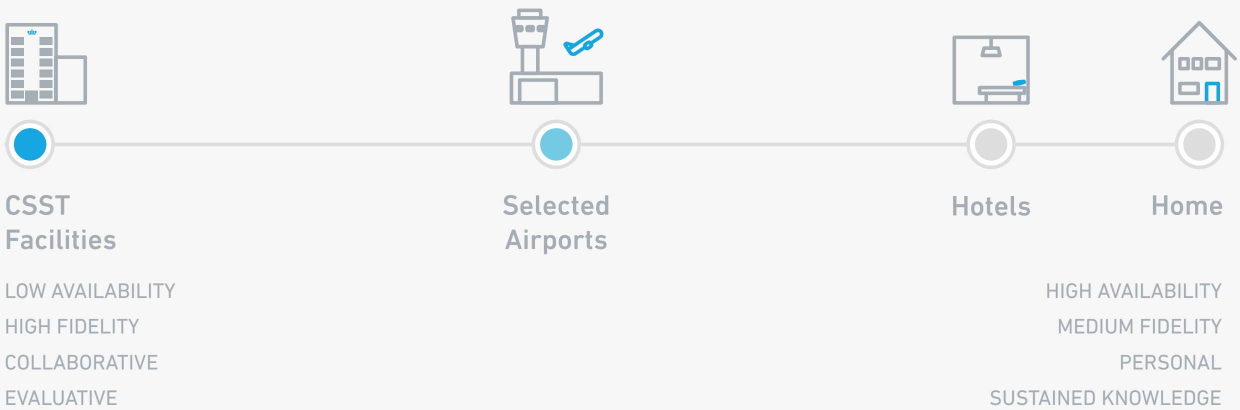


Fig.92 Considered training locations, with a trade-off between availability and fidelity

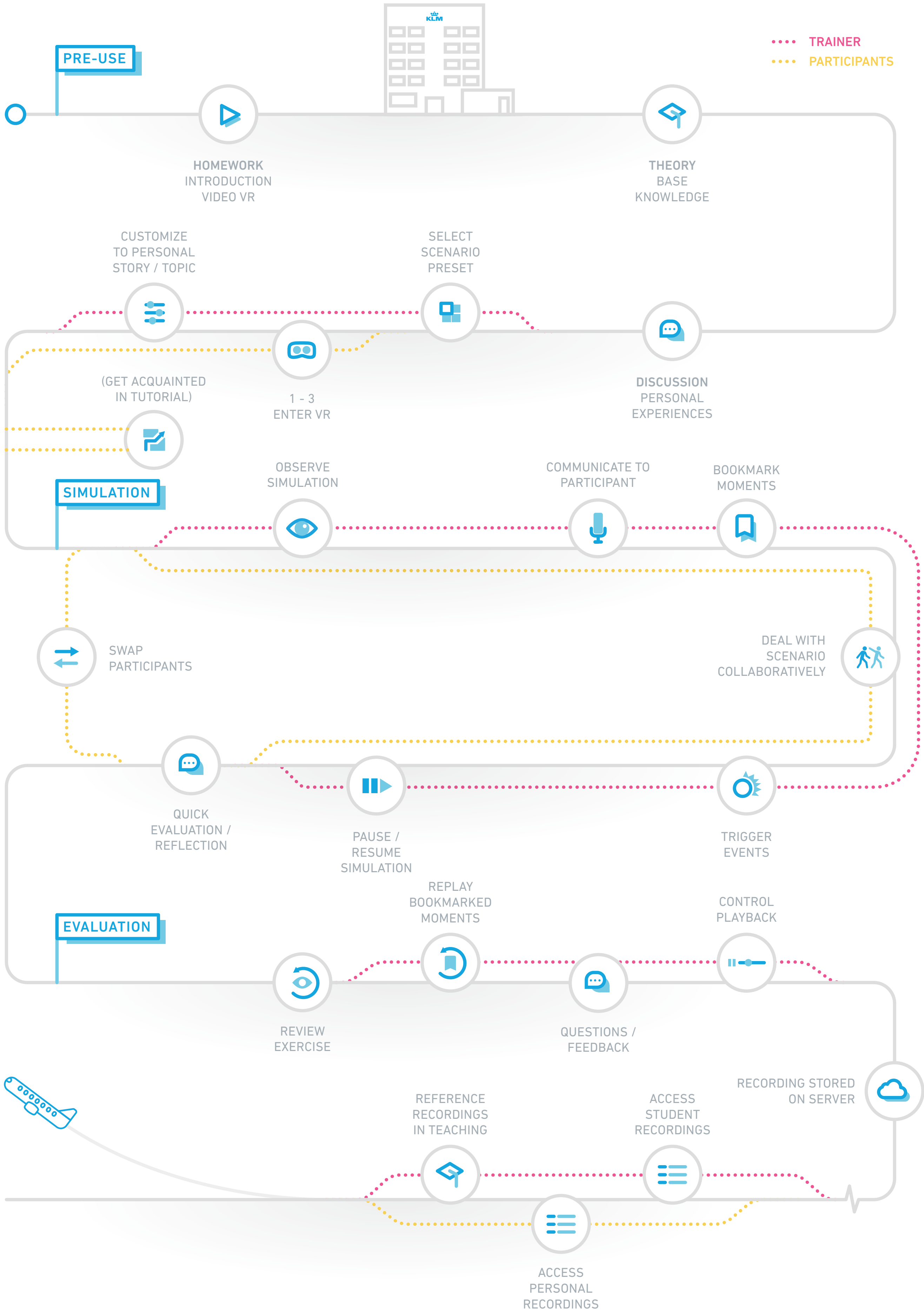


Fig.94 User journey of trainers and participants in a training day involving VR (or AR) simulations

Pre-use

The user journey, visualized in **Fig.94**, is divided into three parts: pre-use, simulation and evaluation. Pre-use includes all steps leading up to the start of a simulation during a training day, and concerns how the simulation is connected to the teaching.

During a training day, the coverage of topics is typically started with a recap of base knowledge of procedures, then switching to the recounting and discussing of personal experiences or real-life occurrences of such emergencies.

Connecting these recounts to the content of the simulation is a large opportunity of a VR system where within the cabin context scenarios can be programmatically generated. The VR system should provide a tool to create and adjust these scenarios, for instance to resemble the (personal) recounts, as this enables both a more tailored learning experience and an increased sense of realism. This tool takes the shape of an iPad app, the design of which is covered in the chapter 'Create, control, evaluate'.

During the user study it became clear that on-boarding VR can be lengthy, particularly when the user lacks familiarity with VR. Several things can be done to ease this process:

- **Introduction video:** a video introducing the VR simulation is helpful tool to communicate the purpose and use of the system. It can be shared on the KLM news app or be watched as homework or in the classroom.
- **Interactive tutorial in VR:** The user study showed it is difficult to understand VR interaction paradigms without actively trying them. An interactive tutorial can be used to guide the user through the different interactions (e.g. moving, teleporting, grabbing / using).

Both steps would only be necessary upon first use, or as a potential refresher for participants. To limit the time lost on the tutorial, it should either be a skippable part of the VR simulation, or a separate VR setup which participants can use when they are waiting for their turn to do the simulation exercise. The latter would save time in the first year of use, but may not see much use afterwards.

As the trainer configures the scenario (or selects a saved, predefined scenario), between 1 (for individual exercises) and 3 (for ABC procedures) participants enter the VR environment. When ready, the trainer starts the created scenario.

Simulation

There are three distinct roles during the simulation: the trainer, the participants (in VR) and spectators (the remainder). The participants are expected to (collaboratively) act according to procedures and their best professional judgment as the scenario unfolds (as described in the 'simulation design' chapter). The trainer facilitates and controls the simulation, and observes what happens together with the spectators.

Simulation control

Trainers have different styles of facilitating simulations, and value a level of control: some interrupt simulations to discuss what was happening, some try to introduce elements of surprise and others guide and communicate to the participant. The simulation control, implemented in the same iPad app as the scenario creation, offers trainers ways to:

- **Communicate to the participants:** the trainer can provide information at different levels of explicity, from (contextual) hints in the virtual environment to orally communicated instructions.
- **Interrupt and resume the simulation:** it often happens that something happens in simulations that warrants direct discussion. Trainers are enabled to freeze the simulation at any point in time.
- **Bookmark moments for evaluation:** On the other hand, frequently it is better to let a scenario pan out and evaluate afterwards, to allow participants to experience the consequences of their actions. A bookmarking function is available to allow a return to specific point during the evaluation.
- **Trigger events:** Besides the creation of the scenario, an ability to trigger events (e.g. fires at specific locations) during the simulation results in a more challenging and personal training.

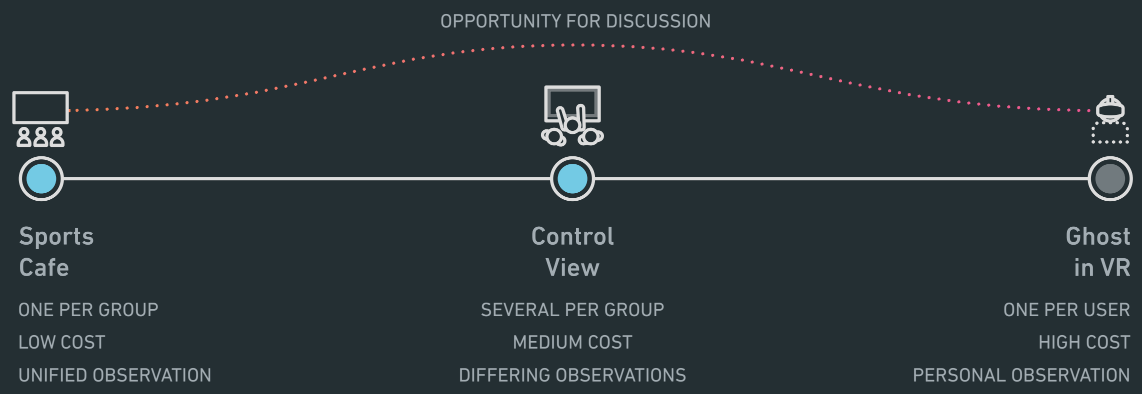


Fig.95 Potential form-factors of spectator view

Spectator view

To know what happens in the simulation, it is necessary to be able to look into the virtual environment. This is primarily done using the spectator view, for which several form factors were considered (see **Fig.95**):

- **Sports cafe:** The simplest solution is to present the virtual environment on a television screen, either from the point of view of each of the participants or as a standalone view (as in sports broadcast). This is affordable and simple to implement, but would leave spectators with relatively little opportunity to individually engage with it actively.
- **Control view:** A second approach is to give groups of spectators control over what how they view (control over virtual camera and perhaps a degree of influence similar to the simulation control tool) using a large touch screen surface. As a result each group can observe different things and discuss freely what is going on.
- **Ghost in VR:** Alternatively, each spectator could observe from within VR as invisible characters, creating the most immersive, personal viewing experience. However, this removes most opportunity for discussion during the simulation and is wildly impractical with most current technology.

The exact design of the spectator view is out of scope for this project. Giving the spectator more control or involvement is likely a good direction to head into, but for now the role of the spectator will be assumed as observing and evaluating what happens in the simulation (as in 'Sports Cafe').

Evaluation

During typical training activities there is little opportunity for (peer-)evaluation, due to a lack of time and tools. The triviality of recording everything that happens in VR makes it possible to review, but the available tools should ensure that this can be done efficiently. Several options were considered, with different radicality (see **Fig.96**):

- **Bookmark Review:** The most conventional solution is to collectively review what happened by replaying moments bookmarked by the trainer (and participants). This allows for detailed reflection, discussion and feedback, but is rather time consuming.
- **Comment Stream:** in recent years a new interaction paradigm was introduced for social platforms with a live streaming feature (see **Fig.97**): audience leaving comments in real-time (and other expressions), which are then temporally bound to that moment. Applying this paradigm would not only make for an engaging spectator experience, but also results in a recording with specific personal feedback which can be reflected upon in the participant's own time (time efficient). It would however likely lessen the opportunity for discussion.
- **Automatic Score & Tips:** The most time efficient way of evaluating is an automated scoring model, which could also include tips based on the mistakes the participants make. This would add a competitive element, but could result in a somewhat generic feedback. Additionally, generally scoring models are refrained from in simulations, as there are few clear definitions of good and

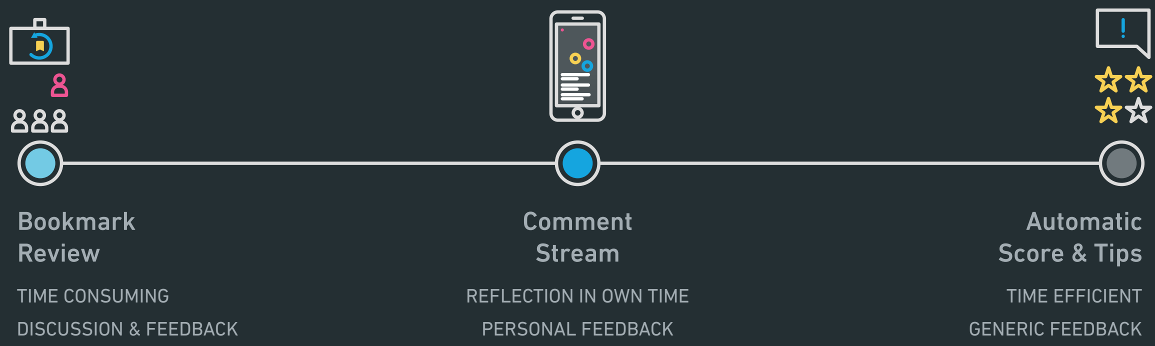


Fig.96 Considered methods for evaluation

bad decisions, and as this does not suit KLM's company culture.

The 'comment stream' has the ability to save time compared to 'bookmark review', but as an additional element complicates use of the system. Furthermore, it is uncertain how likely participants are to later review the recordings of their performance. While 'bookmark review' is similar to current evaluation practices (albeit more systematic), the suitability of the 'comment stream' is a topic for stakeholder validation.

Recordings, including bookmarks / comments, are stored on KLM's servers (if such functionality can be cleared with internal privacy policies). CAs can review their personal performances at any time, for self-reflection. Additionally, recordings are made available to trainers, either for examination purposes or for re-use during teaching: a recording of what happened during a simulation can be illustrative of a point during lectures.

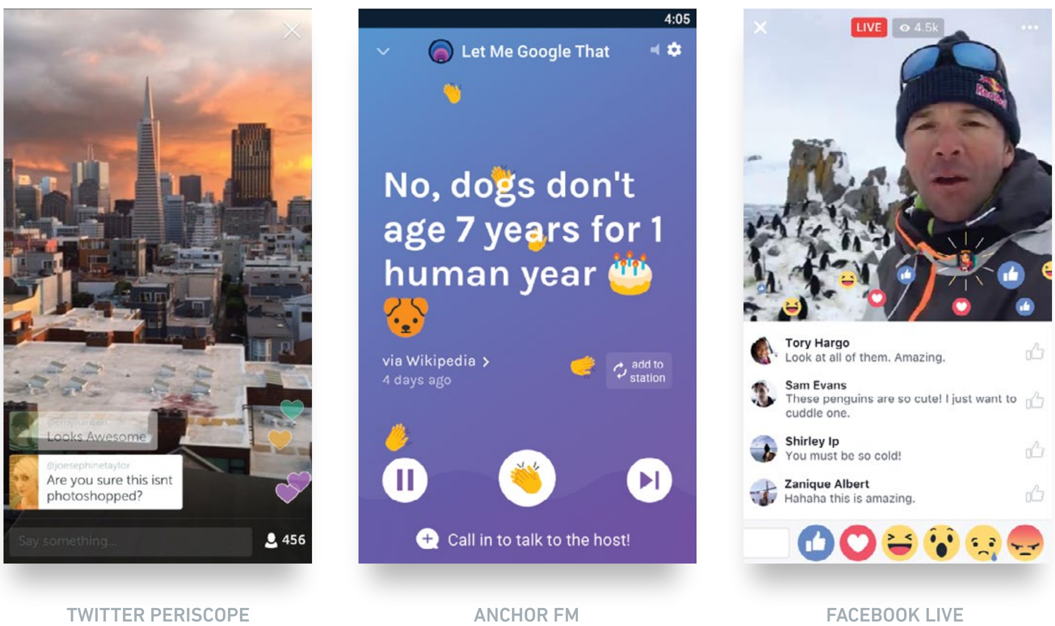


Fig.97 Common Social live-stream paradigm: temporally bound comments and Emoji

Simulation Design Revisions

FROM THE USER STUDY IT BECAME CLEAR THAT VR IS UNLIKELY TO BE AN IMPROVEMENT WHEN MIMICKING THE CURRENT, ALMOST DRILL-BASED, TRAINING OF HARD SKILLS IN THE MAJORITY OF SIMULATIONS AT CSST, AS IT LACKS IN THE REFINEMENT AND PHYSICALITY OF INTERACTIONS.

Rather, its potential lies in the depth and variability of scenarios it can simulates, requiring professional judgment and dealing with stress and uncertainty. The proposed simulation design was revised based on this and other research findings.

Consistent interactions

Understanding the controls and interactions was among the most challenging tasks for the study's participants. Firstly, the difference between the function of the circle button of the left (teleport) and right (UI pointer) controller caused confusion, and most users assumed they could click the floating button by literally tapping it with the controller. To improve this, both controllers were mapped to the teleporting functionality, while the UI pointer was removed in favour of direct interactions between the controller and UI. A second change is the more consistent use of the 'grab' interaction, as in this revision it is also used to open doors. The remaining use of the trigger button is secondary actions (e.g. using the fire extinguisher)

Fig.98 Impression of VR simulation used for poster

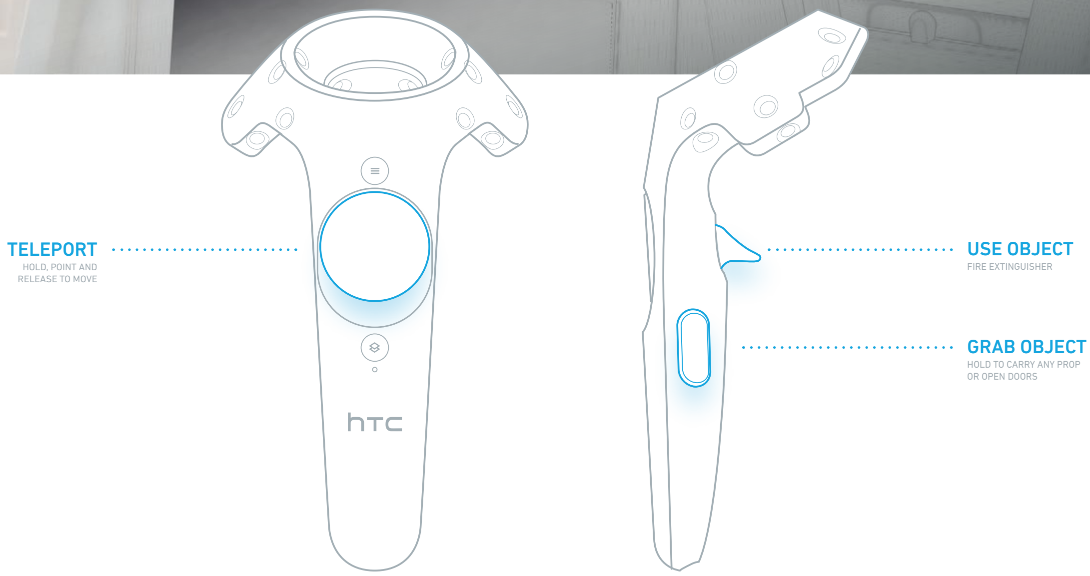


Fig.99 Revised control scheme.

Several physical inconsistencies caused bugs or confusion. For instance, the fire extinguisher could be dropped through the floor, and overhead compartments were either opened or closed completely. The latter prevents the proper execution of the procedure for fires in overhead compartments, which requires putting the door ajar, and closing it immediately afterwards. To solve these issues, the physics-based interaction framework NewtonVR was implemented (Tomorrow Today Labs, 2016). The updated prototype includes granular control over doors by grabbing the door handle and moving, as well as a sound engine that produces collision sounds when objects bump into each other.

Fig.100 An empty Boeing 737 galley storage area from Jamco (Ostrower, 2014)

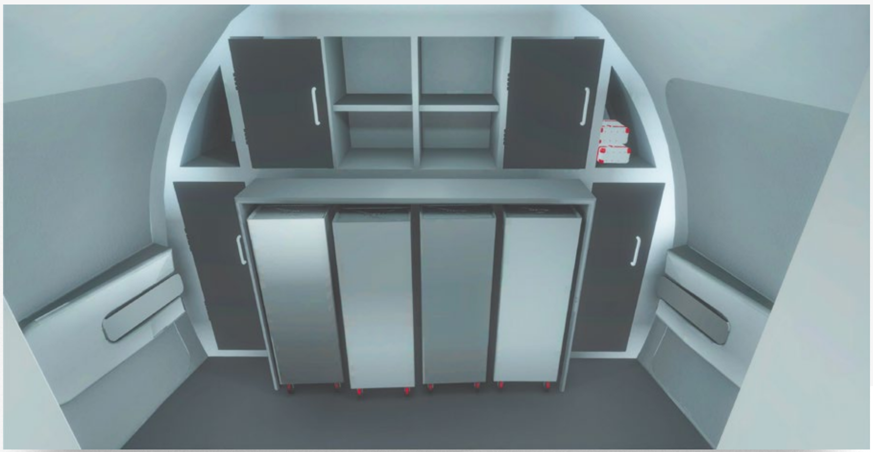


Fig.101 Simplified galley for Boeing 737, with suggested level of abstraction

Reality conform environment

While it is not necessary to replicate every detail of real aircraft cabins, overall consistency turned out to be important. For instance, equipment should be placed in its official location, but its functioning or storage method can be somewhat simplified. In general, the implementation should facilitate aspects relating to decision making, but can abstract aspects related to hard skills. **Fig.101** shows a simplified implementation of a galley storage unit, removing the locking mechanisms and reducing the number of compartments.

Furthermore, it can be considered to implement the cabins of various aircrafts, to accommodate type training (e.g. the RF recurrent). This is fairly simple, as the majority of components (chairs, equipment) can be reused between them.

Passengers

A regular comment on the preliminary design was the lack of passengers: users assumed it would add to overall realism and immersion if the cabin was properly filled. However, this is a challenging topic: for one, creating humanoid characters that behave naturally in the context can be laborious. Secondly, with current technology it is not possible to create a virtual avatar that is convincingly human in both looks and interaction. Approximations typically end up in the so-called uncanny valley (see **Fig.102**), where small inaccuracies can cause revulsion and feelings of eeriness in the observer (MacDorman & Ishiguro, 2006). Still, it is uncertain where humanoids in VR would fall on the curve.

To test this, 12 different humanoid models were generated using Adobe Fuse and used to populate the cabin (each duplicate, for 24 passengers in total). Several character animations of both seated activities (talking, resting, typing, etc.) and distress (shouting, panic, confusion) were collected

Fig.103 Virtual Passengers in the simulated cabin environment

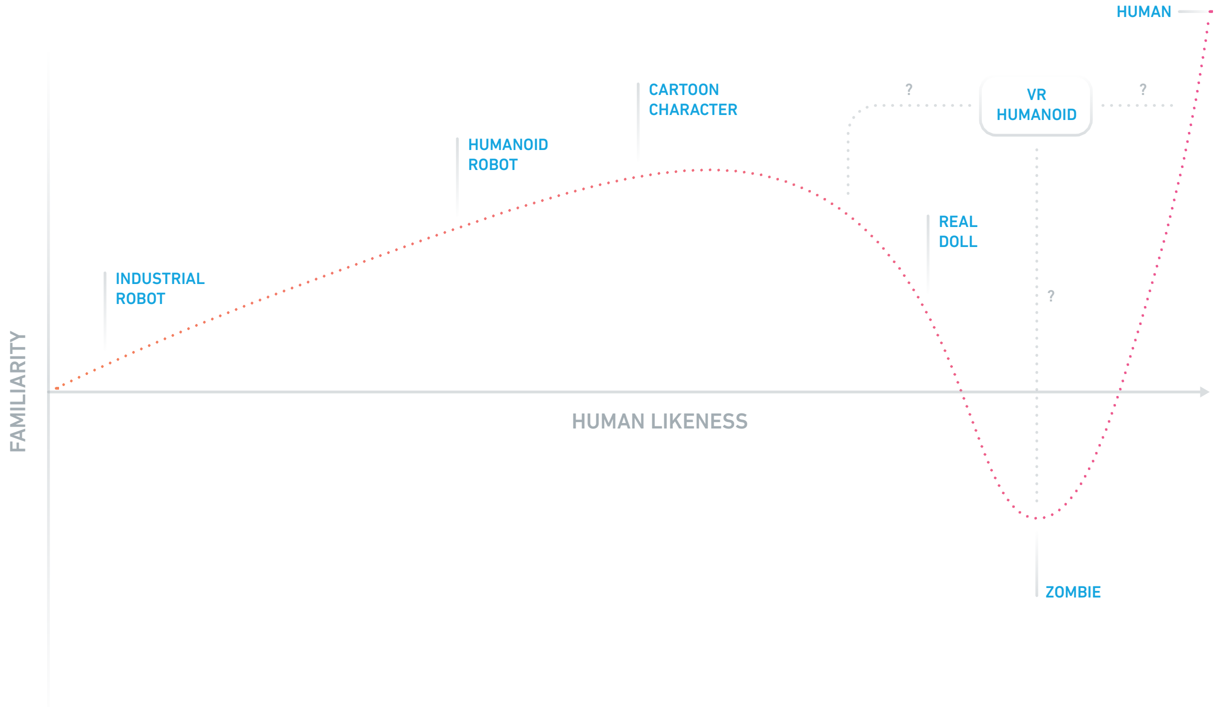


Fig.102 Uncanny valley with several examples and the uncertain place of humanoids in VR.

from the Mixamo platform. The characters were programmed to play either set of animations (depending on the situation) in a randomized order, to ensure entropy amongst the passengers.

In the current implementation, the virtual passengers don't roam around the cabin, or interact with their environment, as these would make animation much more complex. Before such an effort is made, the added value of these characters should be evaluated (see 'User Validation').

Fig.104 Serving safety tasks and detecting medical emergencies as an alertness training

Fig.105 Bomb threat scenario from alert to building a construction at the place of least impact.

Alternate scenarios

To make the simulation remain unpredictable upon extended use, a diverse set of events needs to be available for scenario creation. An exploration was done of which types of emergency can effectively be simulated within the VR cabin environment (see **Fig.104** and **Fig.105**). Some examples include:

- **Explosives:** From the moment of discovery to the building of a construction (platform, wet towels, etc.) to store an undetonated explosive in the place of least impact (door in the back of aircraft), an in-flight bomb threat is a scenario that requires some inventiveness, depending on what materials are available. It is also something that can be simulated relatively well with basic VR interactions.
- **Medical emergency:** Recognizing symptoms amongst passengers requires attention during regular procedures or other situations. Implenentation would require the animation of different symptoms, which is labour intensive but feasible. However, this is largely meant as observation and communication task, as VR is less suitable for the simulating treatment realistically.
- **Serving Safety:** Regular tasks, such as serving consumptions from a trolley, are suitable for VR implementation, but mostly offer a good opportunity to test observation skills and response to safety hazards (e.g. misplaced luggage) or emergencies during normal working circumstances.

Fig.106 Screenshot of spectator view with avatar representation for 2 users

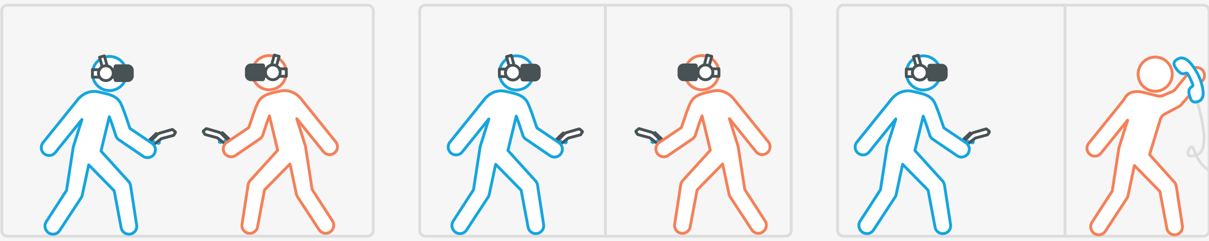


Fig.107 Considered VR collaboration approaches

These should ideally be mixed and matched in the scenario creation tool of the Simulation Control app, to contextualize the emergencies and create more complex scenarios. For instance, a scenario could start with a serving task, followed by the discovery of an explosive and a subsequent panic attack in a passenger. However, it remains the case that scenarios relying on more intricate social interaction or simulation of human behaviour (e.g. unruly passengers, emergency evacuations) are less suitable for the medium at this point.

Collaboration

Several approaches were considered for collaboration within the VR environment:

- **Shared physical & virtual space:** Sharing the virtual and physical space for collaborators would allow for quite direct interaction and communication. However, it would make certain functions, such as teleportation, impossible due to inconsistencies between what happens in virtual and physical space.
- **Shared virtual space:** Multiple users can share the same virtual space in VR, while being in different physical spaces. This is suitable for remote training, but can also be used within the CSST facilities (as it prevents people from bumping into each other).

- **Remote assistance:** It is not necessary for all participants to be in VR for collaboration. In certain (but not all) scenarios, the B & C roles could be performed by spectators, delivering remote assistance (communication, triggering supply of equipment).

Photon, a network multiplayer platform, was used to implement real-time collaboration with the shared virtual space design (see 'Architecture'). This basically synchronizes the state of the simulation between multiple VR setups. When a user interacts with a virtual object, he / she takes authority over it, transmitting what happens to any other user. The users themselves are represented by an avatar, comprising an abstract head and set of hands (see **Fig.106**). This is done because the deriving the full body posture from just the hand and head positions is nearly impossible, and is similar to the 'Avatars' approach taken by Oculus (Oculus VR, 2016).

The networking ability is additionally used for implementation of the spectator view: When a computer runs the simulation, but there is no HMD connected, it automatically becomes an invisible 'spectator', following the avatars off the VR users around in a split screen view (see **Fig.106**) (assuming the 'sports cafe' design of the spectator view).

Conclusion

This chapter includes a number of design and implementation revisions and additions, based on observations and feedback during research and development. The ease of iteration, given that it is largely just software, makes it a recommended approach to start with a minimum viable product (MVP), and continue with such enhancements down the road. This lowers the risk of investment, and allows for the collection of data on what works and what doesn't. The latter is also done with the current implementation, in the 'User Validation' chapter. This user validation uses the final state of the prototype, which is available in the code repository discussed in appendix G.

Fig.108 In-game screenshot of passengers in cabin

Create, Control, Evaluate

TO UTILIZE THE VERSATILITY A VR SIMULATION SYSTEM, BUT KEEP ITS USERS IN CONTROL, A SIMULATION CONTROL TOOL WAS DEVELOPED. THIS TOOL FACILITATES (EXTERNAL) INTERACTION WITH THE SYSTEM PRIOR TO, DURING AND AFTER SIMULATION.

Throughout the user journey, the tool should provide three primary functions:

- **Creation:** prior to the simulation, emergency scenarios can be created, customized and saved, making it possible to have more variable and personally relevant simulations
- **Control:** after starting the simulation, the tool provides ways to interrupt and alter the scenario.
- **Evaluation:** the tool provides access to user recordings, and aids in the evaluation process

Additional Criteria

Besides the general criteria (of which ease of use is in this case extra important), the following aspects are important:

- **Versatility:** what degree of control does the solution provide?
- **Efficiency:** how time consuming and impactful are interactions with the tool?
- **Invasiveness:** to what extent is use of the tool in the way of regular (social) teaching procedures.

Fig.109 Creating, controlling and evaluation scenarios in the proposed iPad Simulation Control app.

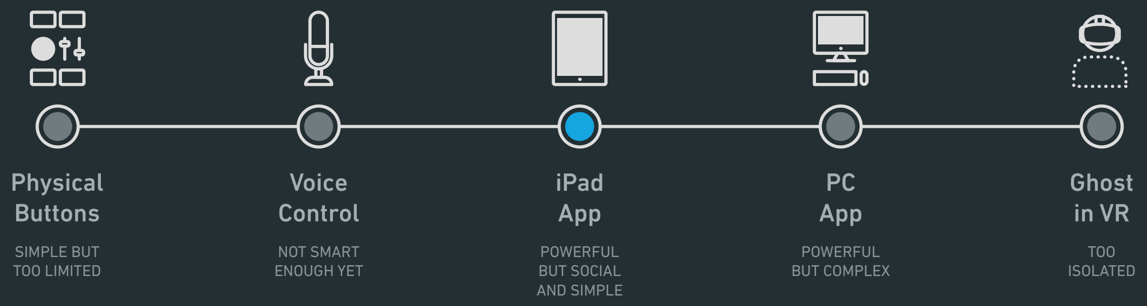


Fig.110 Platform options of the simulation control tool

Platform

Perhaps most defining for the interaction with the control tool is the platform it runs on. The following options are considered:

- **Physical controls:** Current simulations at CSST are controlled using button panels or remote controls, and only occasionally feature a screen. While a robust solution and practical upon repeated use, the control is either very limited or unintuitive due to large quantity simultaneously available buttons.
- **Voice control:** The promise of virtual assistants (e.g. Siri, Alexa) is that they are able to understand and act upon spoken natural language. While it is theoretically possible to describe an emergency scenario and having it then be simulated, voice control AI is not at the point that it is suitable for lengthy, contextual use where the user can speak freely without direct interactions.
- **Tablet app:** A tablet app can provide relatively versatile control, whilst retaining intuitive interaction paradigms and being unobtrusive in a social context. Furthermore, KLM and its personnel already utilize iPads on a large scale.
- **Desktop PC:** PCs are able to run powerful software, but this typically comes at the cost of simplicity and time efficiency. The military VR training by RE-Lion includes a desktop software solution with detailed terrain and scenario editing tools, but this type of solution has too significant a learning curve.
- **VR:** It is also possible to give the trainer an (invisible) presence in VR (a technique also applied at RE-Lion). This would provide unity between the trainer's tasks of evaluating and controlling the simulation, but can result in a loss of overview. Additionally, it would isolate the trainer from the rest of the participants.

The most suitable from these seems to be the iPad. The fact all flight and cabin crew at KLM use one dramatically eases adoption. Additionally, the interfacing between the iPad and the simulation could also be used to provide a similar set of functionality to training participants, rather than just the trainer. This could, for instance, realise the comment stream idea (see 'User Journey'), or democratize the simulation control.

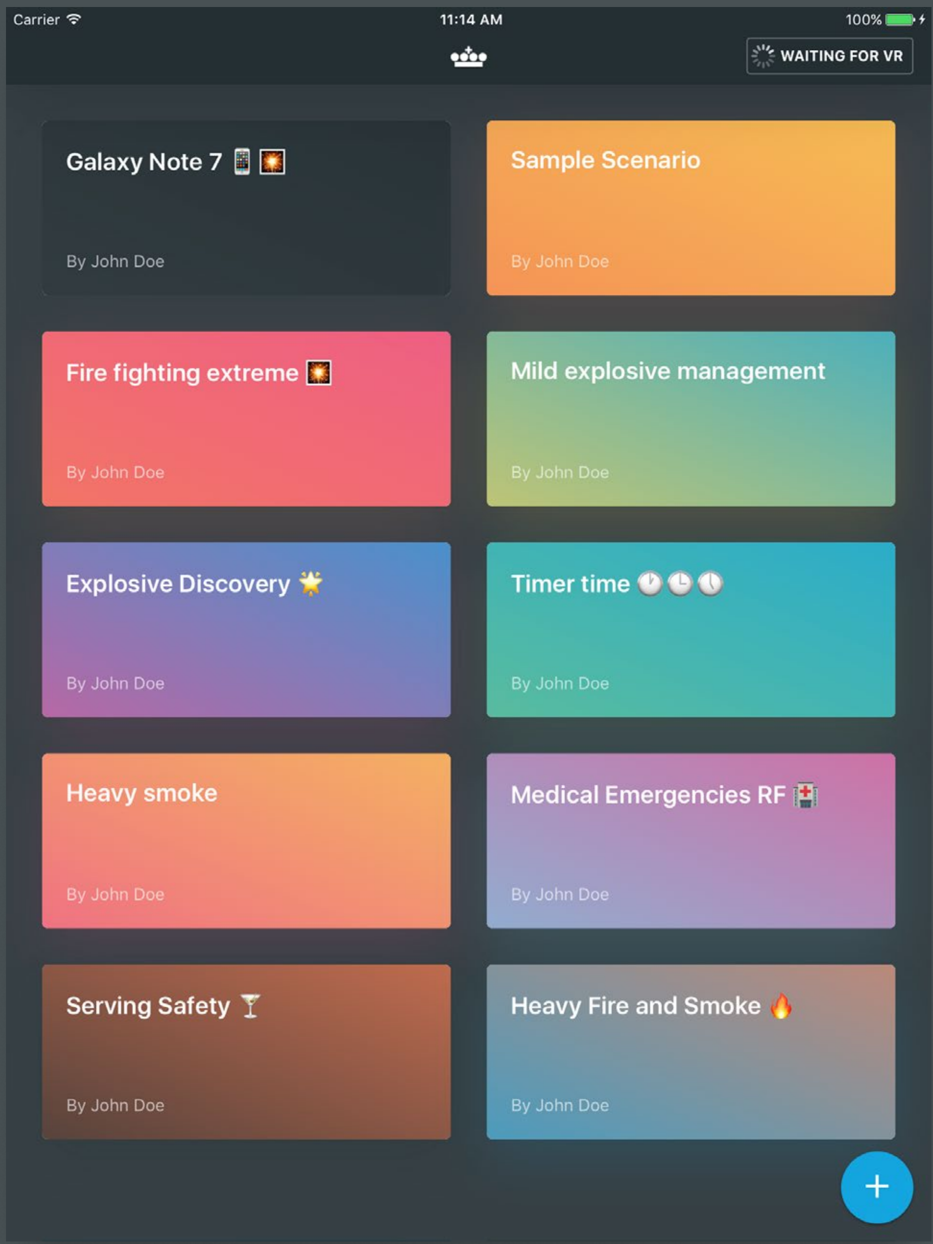


Fig.111 Scenario selection screen

Scenario Selection

The scenario selection screen, which opens when the app is started, presents all previously created scenarios saved in the database. Clicking one takes you to the scenario's overview screen.

Several screens in the app feature a primary action button in the bottom right. In this case it opens the scenario editor screen.

Unwanted scenarios can be deleted by swiping the card to the left and confirming the removal in a pop-up dialog.

Lastly, the top-right of the screen the connection status of the app to the VR system is displayed, indicating whether simulations can be started.

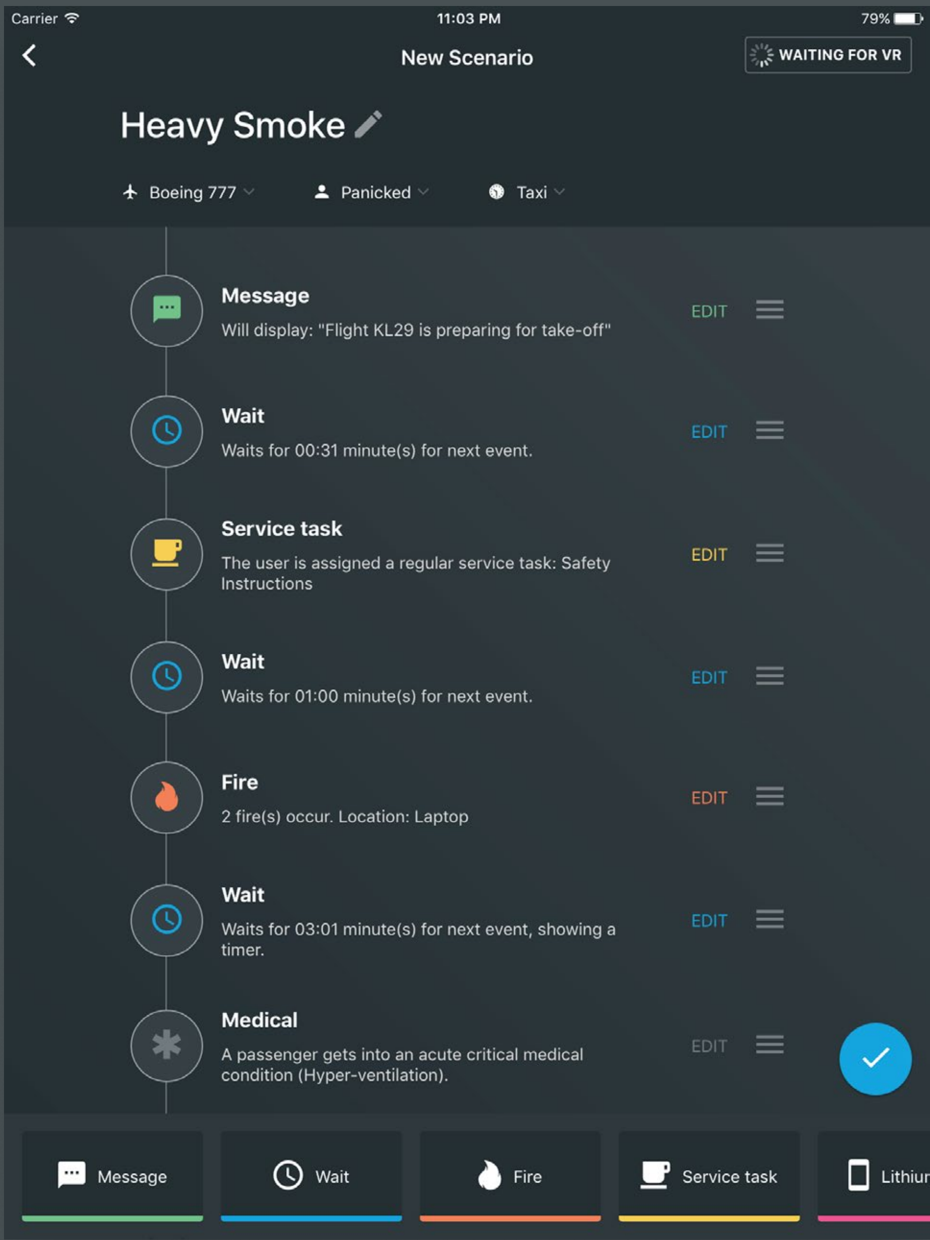


Fig.112 Scenario creation flow, with a block based time line

Scenario Editor

Scenarios are approached as having fixed properties and a time line of events. The scenario editor aims to allow simple configuration of both.

The fixed properties are configured in the header section. These include properties that may have impact on the decision making and execution in VR, such as the aircraft type, the moment during the flight the scenario takes place, or the behaviour of passengers (e.g. docile or panicked).

The time line consists of modules which can be added from the bin on the bottom of the screen. Each module (fire, medical emergency, delays, messages, discovered explosives, etc.) has several parameters (e.g. the location of the fire, or whether or not the 'Wait' module displays a timer). Modules can be ordered by dragging and deleted by swiping to the left. All modules have a default value, and a scenario, such as the one above about heavy smoke development resulting in a medical emergency, can be created with a few taps.

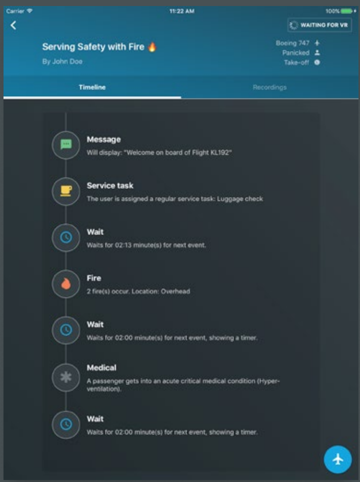


Fig.113 Scenario Overview: Timeline

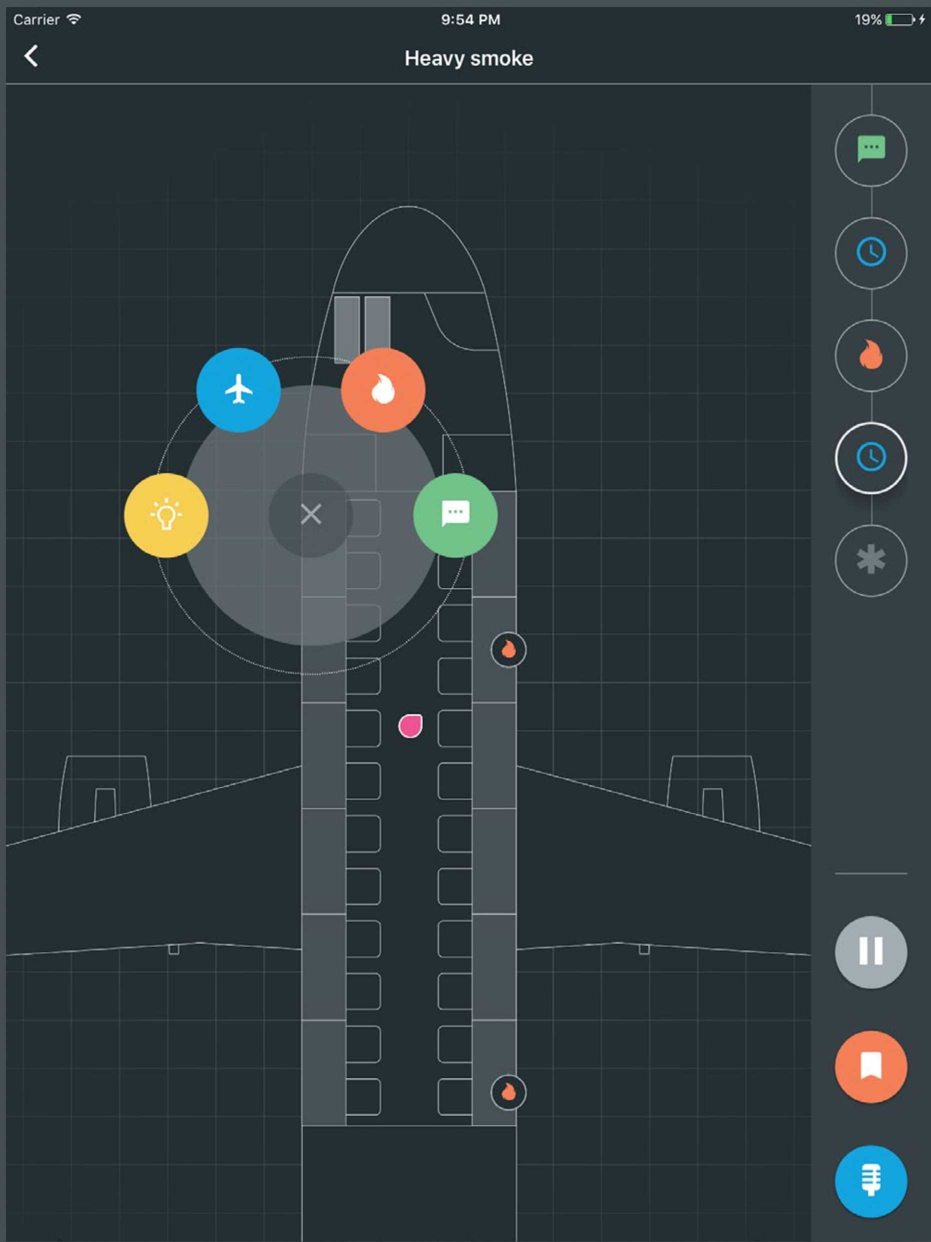


Fig.114 Real-Time Control View

Scenario Overview

When a scenario is created or selected, the scenario overview is opened. This screen provides both an overview of the time line and a list of all recorded performances bound to the scenario. Selecting a recording opens the scenario playback view, while pressing the action button in the bottom right starts the simulation and opens the control view

Scenario Control

The control view presents a top-down overview of the simulated environment, including a real-time location of the participants and on-going situations. Localized triggers (e.g. highlighting a certain area to the player) can be done using the radial menu that pops up when pressing on the map. The bar on the right provides the progression of the time line, as well as three primary actions: pausing / resuming, creating a bookmark, and holding to speak through the virtual intercom.

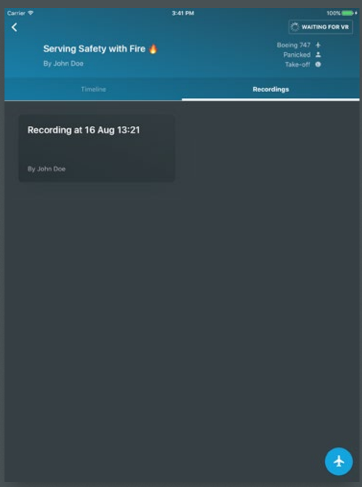


Fig.116 Scenario Overview: Recordings

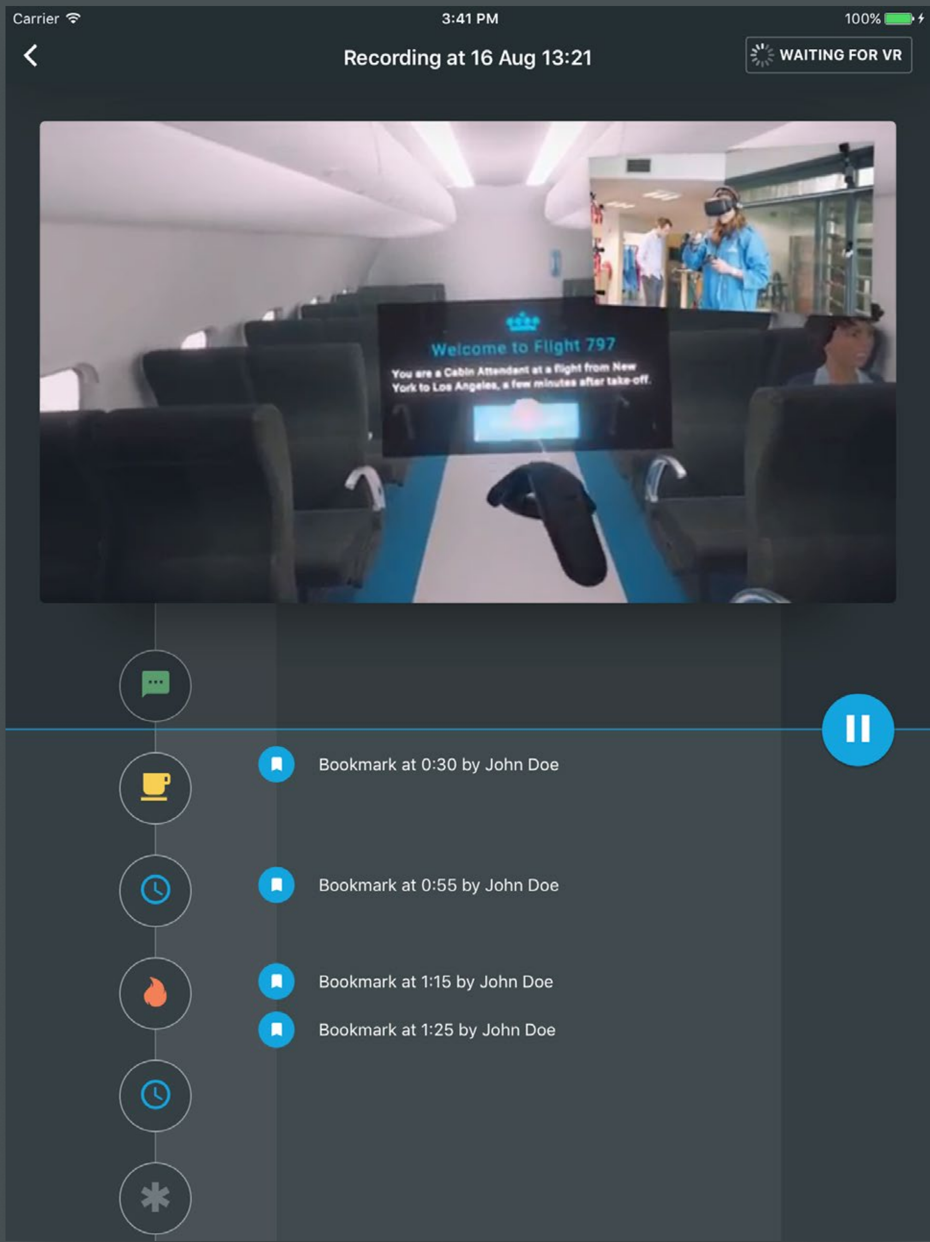


Fig.115 Scenario recording playback

Scenario Playback

Recorded performances can be played directly from the app, or streamed to the spectator view. It plays the recorded perspective of the participants, in connection to the scenario time line and made bookmarks and comments

For consistency with the vertical time line orientation throughout the app, the playback goes from top to bottom. The user can scrub through the recording by scrolling, or directly revisit bookmarks or time line steps by tapping them.

The recording is a video rather than raw gameplay data (like the spectator view), for increased device compatibility. It allows the original graphics quality to be retained and integration of wireless display streaming technologies (e.g. Google Cast and Apple Airplay) and the device's sharing platform. Especially wireless streaming to bigger screens may be important for the evaluation sessions after simulation.

Prototype

A functioning prototype of the Simulation Control app was build. This was primarily done to allow trainers to experience how they could teach with the proposed VR platform (see 'User Validation').

The app was build for iPad (but also works on smaller screens) and uses the React-Native framework that enables a quick development flow while retaining a high-performance native experience. The prototype implements the full flow from scenario creation to the real-time control of the VR simulation, although it the scenario playback functionality is only implemented in a demonstrative manner (as no solution to record the VR environment was developed). The code is available in the repository discussed in the code review in appendix G.

Conclusion

While the design does likely communicate empowerment to the trainers (at least over pre-defined simulations), it remains to be seen how well it integrates with teaching practice: does it provide enough control and versatility, or is it perhaps overly complex for the time-pressured training day?

Fig.117 App prototype in use.

Architecture

WHAT INFRASTRUCTURE, SERVICES AND SPACE WOULD MAKE FOR AN OPTIMALLY FUNCTIONAL SYSTEM?

This chapter explores what hardware is required, how it is connected and how components are laid out in the physical space at CSST.

Additional Criteria

In addition to the general criteria, architectural elements were evaluated by:

- **Reliability:** can the system run with stability and little maintenance?
- **Modularity:** can elements be removed, swapped, scaled and added to the system with limited loss of investment?

Fig.118 TPCast wireless transmitter for HTC Vive (HTC Corporation, 2017)

Hardware

Fig.119 presents an overview of the hardware components in the system, in the currently assumed setup.

Per participant one VR setup is required. For the highest fidelity currently available to consumers, the HTC Vive remains the HMD of choice. The included tracking system (Lighthouse) can't be shared between setups as each user gets her / his own designated physical space to move around in. Besides the included controllers, the Lighthouse system has the ability to track custom physical props using the Vive Tracker system.

The simulation could be run on a desktop PC or on a laptop / VR backpack. The former is more affordable and easily upgradeable, while the latter allows for free movement without a cable getting in the way. However, several add-ons to wirelessly use a VR HMD with a PC are available from companies like TPCast (see **Fig.118**) and Intel (Hardawar, 2017). Intel's WiGig accessory is developed in a partnership with HTC (Vive team, 2017), and seems like a good bet for a stable, low-latency solution, while retaining upgradeability and modularity.

Per spectator view (depending on which design is selected for this purpose), a computer and monitor are required (potentially integrated in one device). This addition of a computer is done to avoid putting additional strain on the PCs running the VR simulation.

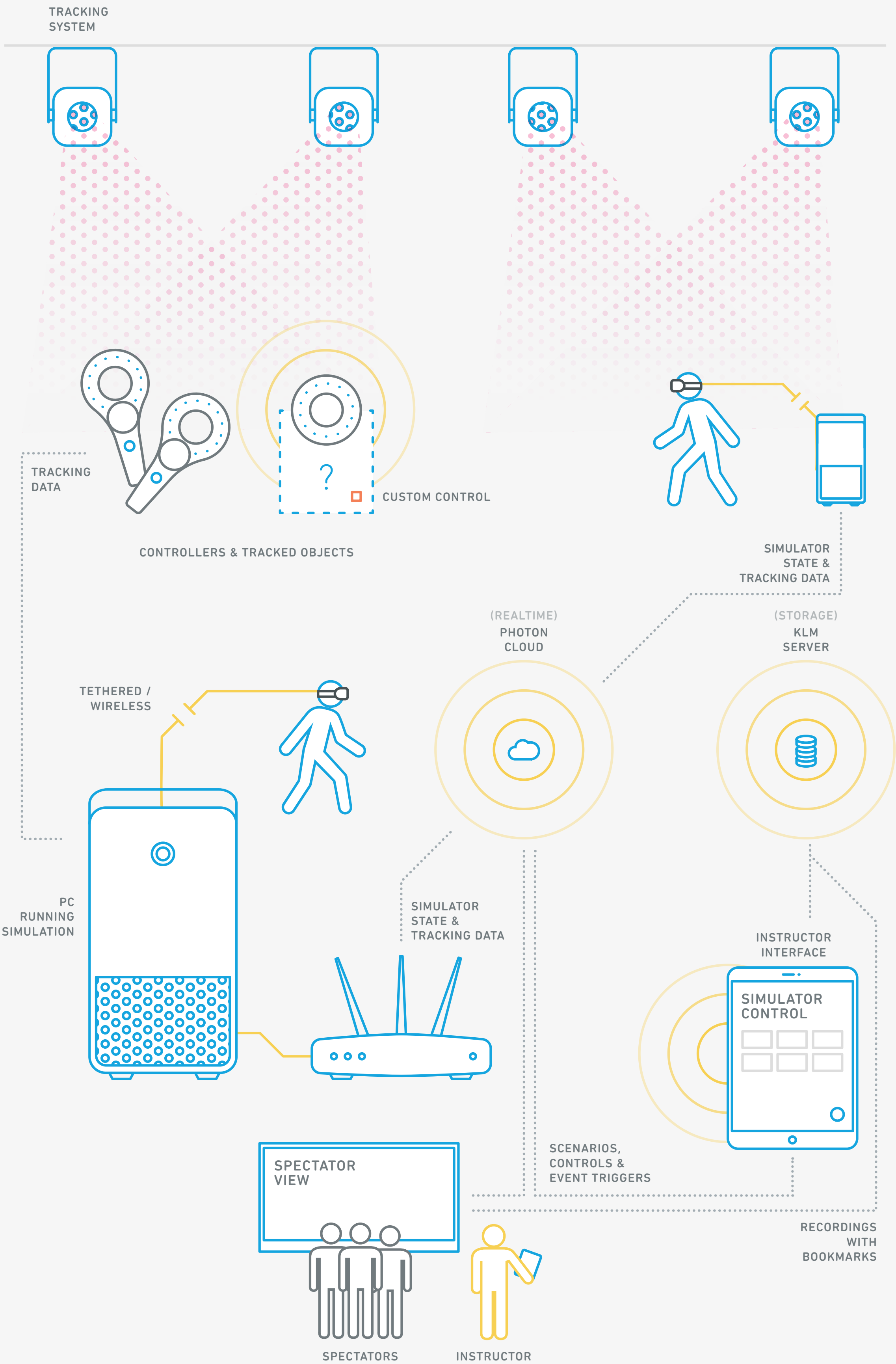


Fig.119 Hardware and connectivity within the proposed system architecture

Connectivity

The connectivity between the components of the system has to enable the following:

- Low-latency, real-time collaboration and communication between players of the VR simulation
- Real-time control of the simulation and voice input by trainer
- Real-time observation of simulation by spectators and trainer
- Storing of scenario presets and exercise recordings

The first three functions require a real-time connection between each interface with the system. In particular for the collaboration, the interfaces need to exactly synchronize the state of their simulations. For instance, if one player performs an action (e.g. grabbing the fire extinguisher), the other interfaces need to be aware of this (including all movement) to maintain consistency. Luckily, several platforms have been developed to fulfill this purpose with next to no latency. Examples are UNET (Unity, 2017), which is part of the Unity game engine, and Photon (Exit Games, 2017). These services don't require building own server infrastructure, but rather rely on an international network of servers using a subscription / tier model. This has the added benefits of enabling remote training facilities and being easily scalable. Photon seems a solid choice, as it is used in a large number of games, and runs on wide variety of devices (mobile, PC) and platforms (game engine, web, app). The latter makes the system flexible for extension (e.g. use in the Simulation Control app).

The storage of scenario presets and recordings (captured simulation footage) requires a simple database and network file storage solution. This could run either on KLM's internal servers or any cloud Platform / Software / Infrastructure as as Service (PAAS / SAAS / IAAS) (e.g. Firebase, Amazon AWS, Heroku, Microsoft Azure). The latter provide a maintained scalable solution for a periodical fee. However, as KLM has an established infrastructure, using KLM's servers would likely be the most cost efficient, integrated and secure way to go.

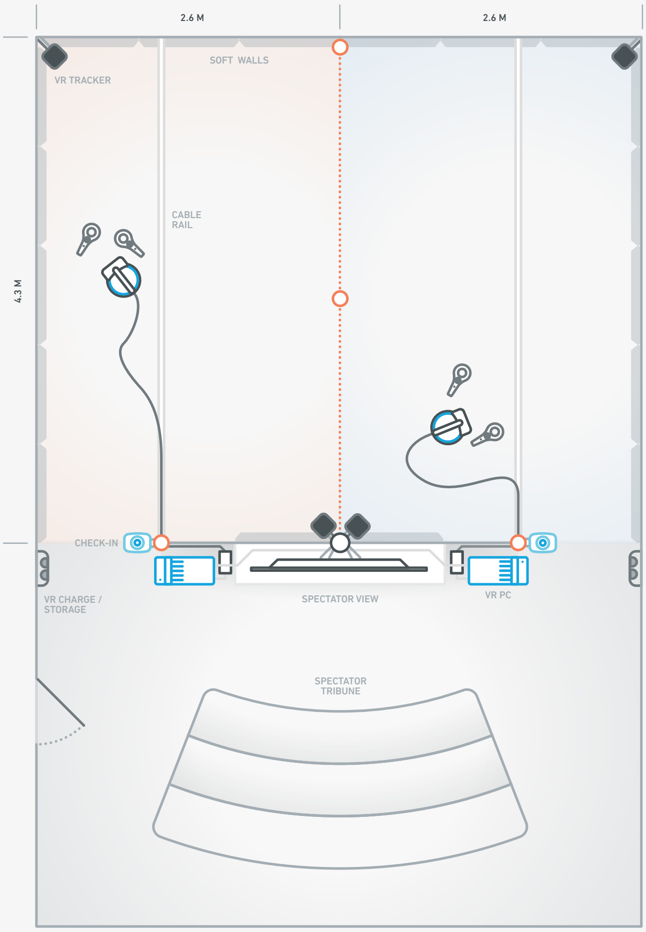


Fig.120 Mockup VR space with single spectator view (tribune)

VR space with single spectator view

When there is a single spectator view, the viewing experience should provide a good view of what happens inside the virtual environment, but ideally also provides a view of what the participants are doing. Placing a divider, rather than a wall, between the spectator area and the VR areas would allow spectators to see both the physical and virtual performance simultaneously. Engagement with the activity could be increased by providing a tribune for spectators to sit on.

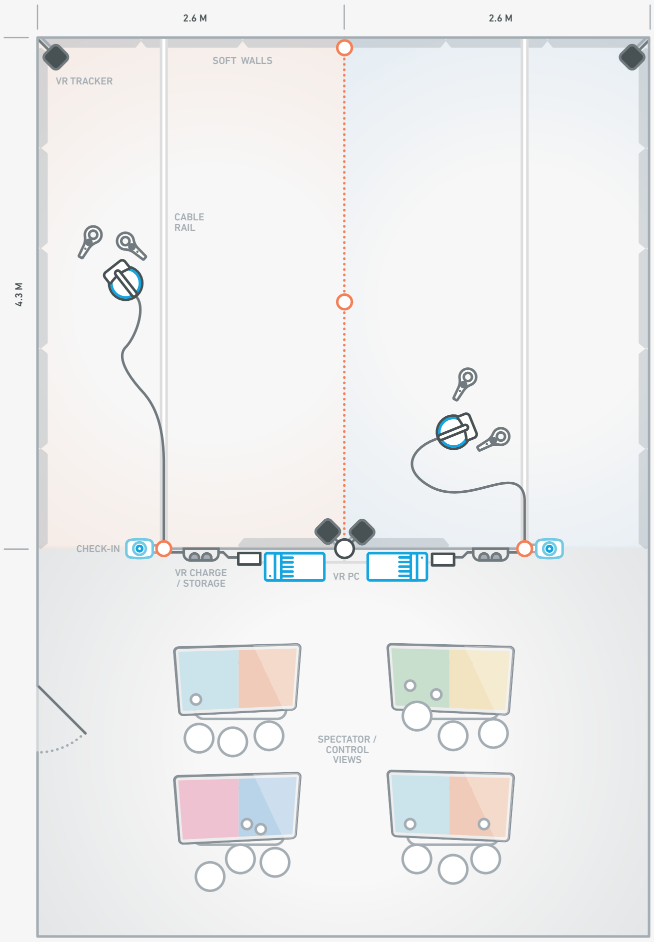


Fig.121 Mockup VR space with multiple, interactive spectator views

VR space with interactive spectator views

In the case of multiple interactive spectator views, utilizing all-in-one computers with a touch screen, spectators split up in groups. These devices typically allow for the screen to be tilted down, allowing for users to stand around and interact with it like a table top.

Space layout

This leaves the question how all required hardware will be placed within the CSST facilities. While design of the designated VR space in the blueprints of the renovation is not a focus point of this project, the following are several considerations to be had and two proposed layouts (depending on the design of the spectator view), displayed in **Fig.120** and **Fig.121**.

One aspect is to enable and encourage free movement in VR as much as possible. The user study revealed the 'Chaperone' system was not sufficiently preventing people from bumping into walls. Thus, the following things can be done to encourage movement:

- **Maximize available space:** the Lighthouse system has a maximum tracked area of 5 meters diagonally. To allow as much lengthwise movement through the virtual aircraft as possible, each VR area could be around 4.3m by 2.6m.
- **Soft collision:** covering walls with a soft material reduces the impact of a bump, and by extension fear to move and risk of accidents and property damage.
- **Cable management:** The fear to trip over the cable can be managed in two ways: a wireless streamer between the HMD and pc, or a cable management solution (e.g. a ceiling mounted cable rail, that gets the cable away from your feet).

To keep the controllers (and potentially the wireless system of the HMD) ready to use and charged a wall-mounted charging dock (see **Fig.122**) can be installed. Putting this dock close to the respective VR spaces ensures the VR sets don't get mixed up.

If recordings of the VR performances are to be connected to the participants (e.g. for evaluation or personal reflection purposes), the system needs to be aware of who is using the simulator. One option is to use a NFC card reader at the entrance of each VR space, to check in with their KLM ID card, although this might be challenging to integrate with the security system. Alternatives include Bluetooth beacons (an ongoing exploration at the CSST department) or manual name entry.

Fig.122 Open design for HTC Vive controller wall mount / charger (Johnson, 2016)

Conclusion

As in-depth specification of required (system) architecture is not a focus point, this chapter can best be seen as a set of recommendations for practical implementation. It also serves as baseline for the cost-calculation in the 'Business Proposition' chapter. In general, it seems utilizing off-the-shelf hardware components and software services in a modular fashion makes a system that can be implemented small and gradually scaled up feasible in the short term.

Business Proposition

THE DESIGN IS NOT A TRADITIONAL FOR-PROFIT PROPOSAL, AS IT IS (PRIMARILY) INTENDED FOR INTERNAL USE. HOWEVER, IT IS IMPORTANT TO CONSIDER WHAT VALUE KLM, AS A BUSINESS, CAN YIELD FROM COMMITMENT AND INVESTMENT INTO THE PROPOSED SYSTEM.

Value Proposition

Learning Goals

As the simulation does not focus on teaching hard-skills, it can't be seen as a full replacement for current (simulation) training activities. It could however improve the overall quality of the programme by assisting in the formulated learning goals:

- **Professional Attitude:** whether the proposed design evokes an increased motivation and serious attitude in training participants is unknown. However, by broadening the scope of the training and making it less repetitive, it is likely to retain attention and show that one can't solely rely on text-book procedures.
- **Tailored Learnings:** The proposed design offers a high degree of accessible customizability during the training, enabling personally tailored scenarios. Furthermore, its evaluation tools could help in the feedback and reflection processes.
- **Professional Decision Making:** The simulation does not necessarily inform participants about emergencies in advance, events can be triggered with a high degree of randomness and scenarios can have unpredictable progressions. As such, users will have to think on their feet. Combined with visual and auditive stress-inducing factors, the simulation can function as stress-resilience training.
- **Performance Evaluation:** It is uncertain how the recording, bookmarking and replay functionalities will be used in practice, but in theory they aid in enabling more time-efficient and visually clear evaluation.

Short-term value

Financially, there are no real short-term benefits. While development of the system (see 'Cost calculation') is likely affordable compared to other simulators, especially given the scalability and maintainability, it doesn't replace those other simulations.

Long-term value

Given its portability, on the long term the system can be used to increase the availability and frequency of training, aiding in sustaining knowledge throughout the year. One way to do this is by making available training spaces in selected airports, where personnel can practice whilst waiting. This may reduce reliance on specialized trainers, but can also be a potential revenue stream by renting these spaces out or licensing the software to other airlines.

Lastly, the system can bring long-term cost-savings, provided VR technology and the software system improve enough to legally replace traditional simulators. This is an incentive to adopt early, and build expertise over time.

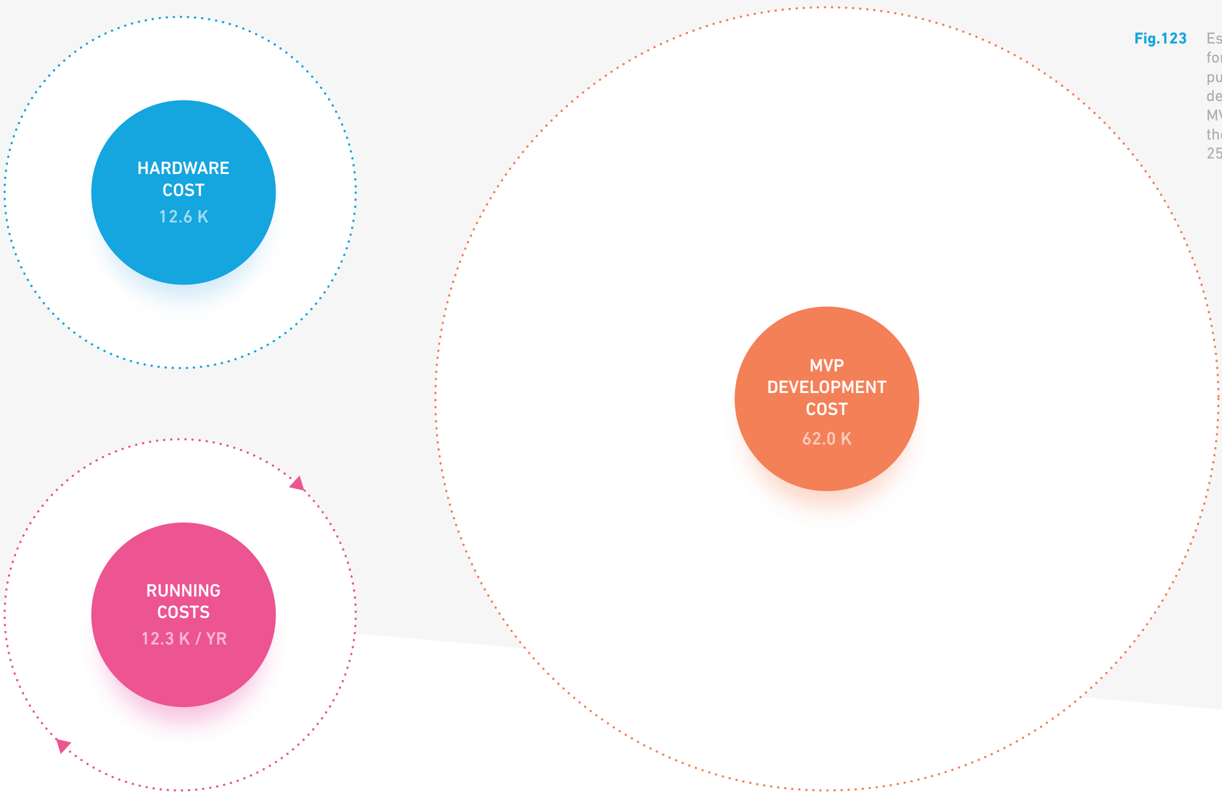


Fig.123 Estimated costs for hardware purchases, the development of an MVP and running the system, with 25% overhead.

Cost calculation

A rough cost calculation reveals that the vast majority of investment is required for development of the software platform (both the Simulation Control app and the VR simulation itself) (see **Fig.123**). The required design and development effort largely depends on the required fidelity and versatility, but even for a MVP this would cost approximately (around 62k euro) five times as much as hardware purchases (around 12.6k euro). This calculation assumes an external agency (100 euro hourly fee) is hired for development, as the project is too big to maintain for freelancers and likely too far out of KLM's expertise to be managed internally. Assuming the design is implemented as soon as a MVP is available, the yearly costs for running, maintaining and improving the system are estimated around 12.3k euro. The cost-calculation is available in appendix E.

Not taken into account for this estimate is the time spent by personnel using the simulator. While the user study and stakeholder analysis revealed current training practice are highly time-pressured, the proposed design uses time and scenario progression as a feature. As a result, even in the simple scenario of the user study, participants spent about twice as much time per simulation round. This may cause a reduction of efficiency, although running multiple simulations in parallel (i.e. having smaller groups) or making the simulation available at airports for use in down-time are ways to counter this effect.

In general, depending on the requirements (features and level of polish) the cost calculation can be altered to end up with any amount between '50 and 150k' for the MVP, but it is most likely significantly cheaper than traditional simulators, and the hardware resources will form a small percentage of overall costs.

6 | EVALUATION

Fig.124 Eostra Stunt Planes (Pexels, n.d.)

User validation

> WHAT VALUE DOES THE DESIGN PROPOSITION PROVIDE, AND HOW WOULD STAKEHOLDERS RESPOND TO THE IMPLEMENTATION AT CSST? A FINAL USER VALIDATION WAS DONE TO GAUGE RESPONSE, ASSESS THE VIABILITY OF THE PROPOSITION AND DISCOVER WHAT REMAINS TO BE DONE.

The user study can be seen as a validation of the preliminary design, but validated only with training participants. Members of the other user group, trainers, as well as other stakeholders within KLM were invited for a validation of the holistic design proposal.

Method

The validation is performed with one or (preferably) two people at the time. All seven participants, get to try out the creation and control of a scenario in the Simulation Control app, as well as the VR simulation itself. Additionally, other aspects of the design are briefly presented and discussed (with a focus on the participant's function). Finally, the participants are interviewed in a semi-structured manner, about their experience and opinions on the design. The questions are qualitative, as the number of participants is quite small and the focus of the validation is on the reasoning and nuances of their opinions. Depending on the role of the participant, some specific questions are asked. The interviews are transcribed in appendix F. The participants of the validation were:

- **Roel van Leeuwen** (Manager CSST)
- **Chris Koomen** (Product Owner VR at KLM)
- **Sam Krouwer**
(Crew Experience / Management Trainee Business & IT)
- **Mirjam Boerop** (Trainer CSST)
- **Femke Hofstra** (Trainer CSST)
- **Crystel Diepeveen** (Trainer CSST)
- **Sander van Geffen** (Trainer CSST)

General Response

The most obvious added value over traditional training in the eyes of the stakeholders was a more complete and realistic simulated environment. According to Femke this would immediately involve psychological factors, while Sander mentions that it would ask less from the imagination because you actually get to experience things you otherwise wouldn't.

While there is a concern amongst stakeholders that some older recurrent participants might initially have a skeptical attitude towards the VR experience, overall they think it makes the training more fun and engaging. Sam also sees it as potentially effective in removing "the gap between their workplace and digitalization". While it is not seen as a replacement of physical hard-skills, but they see it as a way to improve understanding of what can happen, the ability to stay calm and rational in unexpected circumstances and practice how tasks are divided and ABC procedures are executed.

The role of the trainer is expected to become more dynamic, active and reflective, but this will ask a bit more from them. While the trainers in the stakeholder evaluation weren't personally concerned about this, Mirjam and Femke expected around 20% of trainers would not welcome such increased pressure. Handling two things at once (facilitating and evaluating) might be a bit much to juggle. Similarly, the stakeholders expect that for a portion of training participants (mostly recurrent) there will be more skepticism towards VR training, while younger participants would be more likely to embrace it.

Collaboration, which was implemented but couldn't be tested due to a lack of simultaneously available HMDs, was highly valued by the stakeholders, the trainers in particular. Sander and Femke specifically mention that it could be a more effective way of training ABC procedures (provided you can communicate). There is some concern however that this would be an additional complication for participants besides having to familiarize with the VR environment.

The stakeholders came up with many things that could be added to make the simulation more dynamic, like blankets as extinguishing tool, trolleys in the walking lane, the ability to move passengers out of the way. The trainers seemed so inspired (particularly after trying out the demo) that it is recommended to take a co-creative approach to further implementation (at CSST or the Crew Experience department).

The participants strongly connected the passenger noises to the virtual passengers, and felt both added to the overall experience. The look of the virtual passengers wasn't seen as creepy or uncanny, but their behaviour, especially in response to a calamity, was not seen as realistic. The general consensus is that it would become more valuable if you could do some simple interactions with them (e.g. to tell them to get out of the way) as part of the scenario. Otherwise the intractability of the virtual environment aligned with, and in some cases exceeded, expectations of the participants.

Though, as mentioned, there were several ideas on what else could be added.

The controls were much more understandable compared to the first user research, although the complaint about the ergonomics of the controllers (particularly the grip buttons) remains. Additionally, many participants have the expectation for the control scheme to be similar to a conventional game console (Xbox, Playstation), and would map the trigger button to grabbing objects. Some of the stakeholders worried that a subset of training participants would have trouble, and emphasized the necessity of a tutorial. Crystel suggests placing a simplified version at the Crew Centre, to spread familiarity outside the training context (which would be more pressuring).

> *"You feel like you are there, that you really have to do something. You immediately perceive the psychological factors.*
>
> - Femke Hofstra

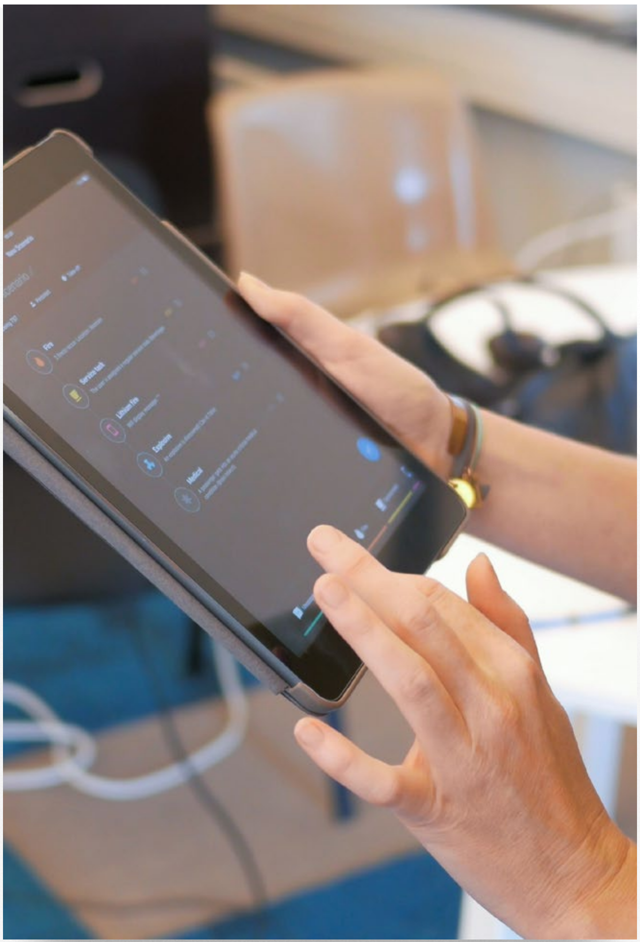


Fig.125 Participant using Simulation Control scenario builder without prior instruction.

Fig.126 Participant using VR Simulation during stakeholder evaluation.

Trainers

Some specific questions were asked to the four participating trainers, on how they image their use of the platform. All would see themselves using the proposed design, mostly as an addition to traditional training. Several expressed their excitement about making the training more personal and relevant. There was some concern how you would use the system with a full class of students, although Sander imagined it would be sufficient to let those not in VR observe, perhaps combined with the task to give feedback. Three trainers thought the training would take up quite a bit of time with both the VR simulation and evaluation, although there are ways to make it more efficient (e.g. smaller groups).

> *"I just had those glasses on, and immediately had like 10 ideas for what else would be possible.*
>
> \- Crystel Diepeveen

The trainers did see both the bookmarking functionality and the recording as valuable, as in current training they have trouble remembering who did what and bringing that up in the reflection. Sander mentioned that the map from the scenario control view of the app would also be useful for evaluation (perhaps side-by-side with the VR recording), so you can have an overview of how a group of participants deals with a scenario collaboratively.

The Simulation Control app was perceived as easy to use but also powerful enough to give a sufficient degree of control. The participants figured out most interactions and functions without prior instruction, while some more hidden interactions (the long-press radial menu in the scenario control view) required a demonstration.

CSST Management

Roel and Sam consider the estimated costs of the system very acceptable, if a bit on the low side of what seems feasible. The general sentiment was that costs can be changed depending on the required functionalities and level of polish. Especially the recurrent training participants would require a high degree of realism and polish, both due to the higher requirements of the training and due to their likely more limited willingness to adopt new technologies.

As such the MVP would need a high level of polish already, before making a bad impression. The safest bet is likely to first implement in initial training, according to Roel, also in regards to replacing mandatory parts of the training. While the VR simulation can't replace mandatory physical training tasks, it can replace or incorporate some smaller mandatory parts of the training. In that, it could also reduce reliance on the physical hardware during those replaceable parts.

There is some interest to seek revenue by licensing the VR software or renting VR facilities out to mid-sized airlines (or KLM's daughter companies), although this would mainly be the business of the 'training facilities' department. Some trainers voiced the concern that having CAs train independently at airports would remove their ability to verify their performance, and risks CAs developing their own 'procedures'.

Crew Experience / Innovation Management

Chris and Sam are seen as people with a broader perspective on innovation projects within KLM. Implementations similar to the proposed design could, according to them, be applied at Ground Services, Service Training and Technical Training. The crew experience department can, according to Sam, also be a very effective way to involve crew in the design process, as they stop by at that department between flights.

Conclusion

Overall, the participants responded well to the aspects of the proposed design, and seemed to understand the intended value well. It also provided several helpful insights on where resources should be invested, and what challenges remain in the integration. Perhaps most interesting was to see how experiencing the VR simulation evoked new, concrete ideas among the stakeholders, more so than in prior interviews without a prototype. At this point, it becomes increasingly valuable to involve trainers in the creative process.

Next steps: a checklist

THE FOLLOWING IS A PERSONAL RECOMMENDATION FOR THE STEPS TO BE TAKEN FOR IMPLEMENTATION OF THE PROPOSED DESIGN AT CSST.

As discussed, a MVP approach is recommended, with a minimal implementation as starting point and subsequent further development and scaling in the following years. A proposed time line for this progress is visualized in **Fig.127**.

MVP

The MVP should function successfully as a training tool and clearly communicate the potential of VR and the proposed system around it. Functionalities that are not fundamental to these goals, are left out.

Project management

- [ ] **Pitch to KLM management**
  To go from experiment to implementation, funding or approval is required from KLM management. To pitch the design proposal, it is recommended to evaluate to what extend the prototypes need to be enhanced to communicate the system's value optimally. Furthermore, a more accurate cost estimation can be made by reaching out to external development agencies.

- [ ] **Enlist designers and developers**
  Given the size and required expertise of the project, it is recommended to outsource the further design and development to one or multiple agencies. Given the specificity of the context, a close ongoing collaboration between KLM and the selected partners (e.g. through a Scrum approach with manager within KLM as product owner).

- [ ] **Define scope of MVP**
  From the user validation, it can be concluded that an initial implementation doesn't have to be feature complete, but should be highly polished. By consulting trainers and participants on their needs and developers on the involved development efforts, a final feature specification should established for the MVP.

- [ ] **Organize trial runs**
  Interim prototypes, as well as the resulting MVP, should be tested with both training participants and trainers. A product owner from within KLM can connect the designers and developers to the users. From the response of trainers during the stakeholder validation a co-creation approach can also be considered, perhaps involving a fixed group of trainers more deeply into the project.

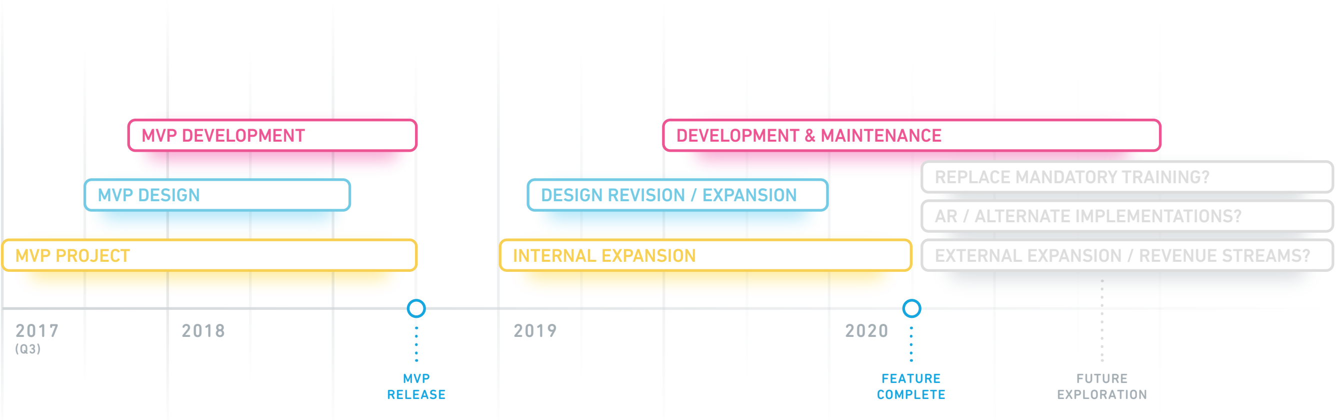


Fig.127 Proposed timeline of the further design, development and implementation of the designed system at CSST.

Design

☐ Select (critical) situations to simulate

The purpose of the MVP is to limit development effort before launch. However, to at least fulfill its purpose, a basic selection of (emergency) events that can be used to create scenarios should be made, as well as a design of how these should be incorporated.

Imagine possible courses of action

To enable a significant degree of contextual decision making, the simulation should enable users to act within and outside conventional procedures. Trainers are a valuable source of knowledge and ideas on this point, and should be involved.

☐ VR simulation design

Evaluate locomotion

While several alternatives were explored, the current solution caused some confusion. A user test with alternative methods or means of communication how one can move can help to improve this.

Create and source 3D assets / sounds / etc for a single aircraft

It is recommended to start with a single aircraft type (but aim for reusable components). The assets that this requires can either be sourced from online repositories or created internally. Contact Peter Huisman for ongoing developments on a shared repository of (3D) assets within KLM.

☐ Co-design evaluation tool

The current design goes into limited depth on the evaluation method, although its core idea is based on brainstorms and interviews with trainers. An additional iteration on this design, focused on how trainers think they can yield optimal learnings from it, is recommended. Regarding the spectator view, for the MVP it is recommended to stick with the 'sports cafe' model given its simplicity.

☐ Tutorial / on-boarding instructions

While trainers can be instructed on the use of the system, training participants have limited time to get acquainted with the simulation in practice. From the research findings, it seems most effective to create an interactive tutorial in VR, at the start of the simulation.

Development

☐ Existing code base vs. starting from scratch

The prototypes (VR simulation and Simulation Control App) implement many functionalities of the proposed design, but are developed largely with experimentation in mind. It is possible to use (parts of) the existing code base for further development, but this may lock developers into the tools and libraries used.

Evaluate available (open source) solutions

Development effort may dramatically be reduced by utilizing existing solutions (as is done in the prototypes)

☐ Implement MVP design

Simulation

Developers and designers should ideally work closely together to deliver a high quality experience, because of how integral experiencing prototypes is to design for VR. A set of activities that the development of the simulation involves is listed in the cost estimation (Appendix E).

Simulation Control app

For the MVP it is important to provide trainers with access to the Simulation Control app on their existing hardware (i.e. Apple iPad). Appendix E includes a list of activities required to accomplish this.

Server Back-end

This a small project, as multiplayer and real-time control is likely facilitated by a service like Photon. Thus, what remains is an internal server application that stores a database with saved scenarios, linked recordings, and user accounts with simple authentication and permission rules (e.g. to determine who can watch which recordings).

☐ Testing and bug-fixing

While an MVP doesn't have to be fully complete, it is important that it has a polished user experience. If there are frequent errors or if the system is not easy to use, user will develop a negative attitude, potentially harming its further adoption. User testing prior to implementation will likely resolve this issue.

Expansion

Project Management

- [ ] **Collect feedback and requests from users**
  As the MVP is put in use, the project manager can start planning what needs to be improved and added.

- [ ] **Decide on scale of implementation**
  At this point it becomes clear how effective VR is as a training tool in practice. To consider flexibility in the design and development, it is important to decide on what scale VR will be implemented at the department. At this point it becomes more important to consider which mandatory parts of the training can be performed in VR.

Design

- [ ] **Interaction method and hardware**
  VR peripherals, such as VR treadmills and motion capture systems, are currently under heavy development and typically have limited availability. While the currently implemented solution likely suffices for the MVP, keeping an eye on these developments is valuable to increase immersion and remove limitations of the simulation in the future.

- [ ] **Spectator experience**
  At this point in time, it is worth evaluating if spectating trainees require more engagement and interaction with the simulation they are watching, and whether concepts like the 'comment stream' and 'control view' (see 'User Journey') should be implemented.

Development

- [ ] **Implement full / refined feature set**

  - **Multiple aircraft types**
    Largely reusing the assets for the first simulated aircraft type, cabins of the different aircrafts flown by KLM should be implemented. This increases applicability for type training, and may help train participants to deal with the differences between these aircrafts.

  - **Additional critical situations**
    The emergency events left out of the MVP can be implemented at a later stage, ideally making the simulation more versatile, unpredictable and reusable.

  - **Implement design for spectator view**

- [ ] **Setup support system**
  As with most technological systems, it requires maintenance and support. While some support can be done remotely, it is recommended to both familiarize engineers internal at KLM with the functioning of the system, as well as have the system's developers check and maintain it occasionally.

Future exploration

The following topics are not within the scope of the proposed design when implemented, but rather are topics that warrant additional exploration:

- Can the system work with other AR and VR devices in addition?
- Can components of the system (i.e. the Simulation Control app and spectator view / recordings database) serve as a universal platform?
- Can the system and simulation design be applied to other learning departments and facilities within KLM (Ground Services, Service Training, Technical Training)?
- Can the system and simulations be adapted for rental to other airlines, either just the software or hardware / spaces at airports, as a potential revenue stream?

Conclusion

IN HALF A YEAR A HOLISTIC PROPOSAL FOR SHORT-TERM IMPLEMENTATION OF VR AT CSST WAS DEVELOPED, AS A STRESS RESILIENCE AND PROFESSIONAL DECISION MAKING TRAINING.

While VR can't replace most of the mandatory, largely physical hard-skills in the department's training programmes, it can create a more complete simulation environment, more closely approximating the challenges of real-world emergencies. As in practice emergencies don't typically occur in a text-book manner, it seems essential to train personnel to deal with unfamiliarity and unpredictability, and have them think on their feet.

The paper written on the user study was deemed of some scientific significance, despite its relatively small scale, and is to be submitted for publication shortly. It certainly provided interesting insights into how people behave in a stressful VR environment. However, it would require follow-up research at a larger scale to be conclusive about whether the increased stress and worsened performance of CAs in a VR simulation is due to an inability to deal with the complex context of emergencies, or due to a lack of familiarity with VR.

The design in this project was frequently approached from a system level, meaning it thinks about VR simulation as a set of components integrated in the training programmes of CSST. In envisioning what roles different users would play, and what tools should be present to facilitate that, a comprehensive concept was envisioned. However, given the time constraints, this broadness comes at the cost of the level to which the underlying solutions are developed and decided upon. This is largely intentional, as the intent of the project was to gauge the value of VR as a training tool in practice, and provide a starting point for further development.

Despite there being no strong short-term financial incentives for the design, the estimated cost of developing a MVP is significantly lower than that of most physical simulators (whilst retaining full creative ownership and the flexibility to change the system year over year). Initially serving as an addition to traditional training, it will improve training by contributing to the selected learning goals (of which the contribution to 'performance evaluation' and 'professional attitude' remain somewhat uncertain). As the system becomes more developed over time, it can likely incorporate some of the mandatory training activities (first of initial training, then recurrent), leading to potential cost savings and lessened reliance on physical simulators. Another road to explore is the implementation of the system outside the CSST facilities, as a way for CAs to train throughout the year, to share a VR platform between KLM's departments, or to seek revenue leasing the system to other airlines.

The VR technology has only recently become popularized, and ongoing developments are progressing at a high rate. Many aspects of the hardware, software and interaction models are still exploratory, and likely to change and improve in coming years. This doesn't mean one should wait with adoption, as the technologies are sufficiently modular to be changed as better solutions come along. Rather, with the projected exponential growth of the market in coming years, it is an attractive position for KLM to be a pioneer.

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