QUANTIFIRE

Smart Technology for Future Firefighters

Master Thesis

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EXECUTIVE SUMMARY

This report aims to analyse the possibilities of smart technology for firefighters and how it can be used to make the firefighter department more efficient and safe. The analysis phase focussed on exploring firefighters' needs and the characteristics of their culture. Besides that, the technological opportunities were investigated, aiming to define the future of firefighting. The outcome of this analysis helped to define the five concepts directions for smart applications: smart communication, virtual situational awareness, contextual navigation, monitoring health and artificial senses.

The monitoring health direction is chosen as the most promising. It has the potential to prevent physiological injuries and it could be a first step towards data collection at the fire department. This could contribute to a more efficient and safe fire department.

On the basis of this design direction, a concept proposal for a smart system is developed: the QuantiFire. This system improves the communication between firefighters by making smart use of digital audio and it helps in preventing injuries from heat related illnesses. Through rapid prototyping and several iterations, the system is embodied resulting in a smart earpiece and a connected smartphone app.

Finally the concept proposal is tested on its core assumptions. This helped to estimate the potential it has on the business, user and technology aspects.

GLOSSARY & ABBREVIATIONS

After-care - The after care phase of a firefighters safety chain consist of preparing for a new alarm, staff care, reporting and PR.

Agile - Agile is a methodology, developed for software development, that focusses on getting the ideas as soon as possible to the customer in order to make quick iterations.

Aircraft firefighting - The first action in aircraft firefighting is to make sure that everybody inside the plane survives by extinguishing fire and by controlling the ventilation, only then the people inside the plane will be saved.

AR - Augmented reality

Building firefighting - Building firefighting is focused on saving victims first. When there is no danger for a person, they would start with extinguishing the fire or let it burn out controlled.

Business Model Canvas - A visual representation of the key elements of the business model.

Contexmapping - Contextmapping is methodology that investigates the context of the customer by involving the user as the expert.

Crashtenders - Crashtenders are specially designed firefighter trucks for aircraft firefighting.

Deployability - In the context of this project, deployability is the ability of the firefighters to be deployed, based on their physical or mental state.

ECG - electrocardiography

Efficient - In the context of this project the term efficient is used to define achieving the goals in the best way with the least effort or money as possible.

Emerging technologies - New technologies that are capable of changing the status quo.

Heat cramps - Heat cramps expresses in muscle cramps due to the exposure to heat.

Heat exhaustion - Heat exhaustion causes exhaustion, dizziness, headache and sometimes loss of consciousness due to the rise of the core body temperature.

Heat illnesses - Heat illnesses or heat related illnesses are the disorders due to the exposure to heat. It contains: heat rash, heat cramps, heat exhaustion and heat stroke.

Heat rash - Heat rash is a reaction of the skin due to the exposure to heat.

Heat stress - Heat stress is the amount of stress the body endures when the body can not lose the heat.

Heat stroke - Causes failure of the body due to the increase of the core body temperature.

Industry influencers - Are the people that has influence on the market due to their status.

Information Journey Map - An information Journey Map, is a graphical representation of the information streams. In this project is is used to define all the information that is necessary at a certain moment.

Interaction vision - Is a representation of the intended interaction that a design needs to provoke.

Key interpreters - Are the people that know the market the best. They conduct research on how people give meaning to products and services and they develop things that influence these meanings. They act as Industry influencers

Morphological chart - graphical representation of the solutions for the sub functions of a new product or concept

New product profile - A new product profile or Harris Profile is visual representation of the positive and negative aspects of a new product or concept.

PPG - photoplethysmography

Preparation - Preparation is in the context of this project used as all preparations for a repression such as exercises and training, maintenance of equipment and deploymentplanning for special objects.

Prevention - In the context of this project, the term prevention is used for all measures to prevent fire outbreaks.

Pro-action - eliminating structural causes of insecurity.

Repression - Repression is in the context of this project used as all activities in order to control, suppress and to prevent expansion of a fire, accidents or disasters as quickly as possible.

Safety - In the context of this project, the term safety is used to define the potential danger for the firefighters themselves, not the victims they need to save.

Smart earpiece - An earplug that contains a micro controller to perform task for the user.

Smart technology - Technology that applies artificial intelligence to input and take some actions.

SWOT analysis - In the context of this project, SWOT is used to define a study on the strength, weaknesses, opportunities and threats of a certain aspect.

Value Proposition - A visual representation of the elements that contribute to the reason a product exist

Values - In the context of this project, the term value is used to define all the elements that contribute the reason a product exist

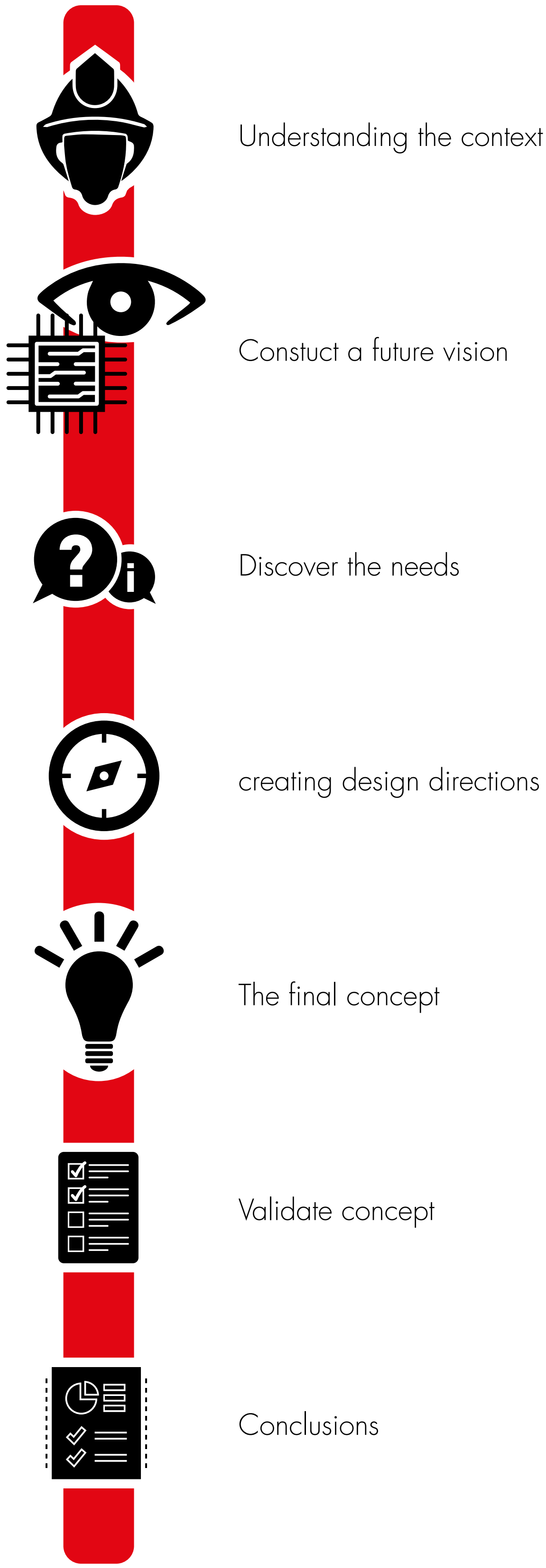

Figure 1. Project structure

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ABOUT THIS REPORT

Purpose

This report is written for Schiphol NeXt, the innovation department of Royal Schiphol Group, and the Fire Brigade of Amsterdam Schiphol Airport, as part of the IPD graduation project.

Schiphol Airport exists for 100 years. In these 100 years, Schiphol changed from a small military airport to one of the most important international airports in Europe. It won almost 200 awards and it scored as one of the best airport in Europe and in the world globally (Schiphol Group, 2017). The ambition of Schiphol is to become Europe's preferred airport, but due to big investments in quality of airports in the Middle East and Asia, it is difficult to become the greatest airport. That is why Schiphol is investing in becoming Europe's preferred digital airport. Both in providing a seamless passenger journey as well as being a progressive smart digital organisation (van Leeuwen, 2015).

Schiphol NeXt is working towards this ambition. As part of the IT department, this department is responsible for stimulating IT innovations at the Schiphol Group. They do this in two ways; identifying interesting opportunities and inspiring other employees to work on innovative projects. It has a hands-on approach, 'Seeing is believing'. This project is a collaboration between Schiphol NeXt and Schiphol's fire brigade.

To ensure an incident at Schiphol has as little effect on the business as possible, Schiphol has an own fire department. They operate in the Schiphol area as a company fire brigade and when needed, they help the national firefighters. Because Schiphol's business depends on the fire brigade, there is a constant need for a more efficient and safe work environment of the firefighters. Since 200 years, innovation for firefighters only happened on materials, comfortability and safety. The use of smart technology is lacking. To research the possibilities of smart technology for firefighters, this project is started.

The project works in two ways. First, research is done on the firefighters needs and the opportunities for new technologies, and secondly a concept is developed based on these outcomes. The main research question of this project is:

How to make firefighting at Schiphol more efficient and safe by implementing smart technology?

The scope of this project

The research question is relatively broad. Therefore the scope of this project is limited to focus on the firefighters direct surroundings and its protective equipment. The focus is on building firefighting although the final product could be used for aircraft firefighting as well.

Overall approach

The context of this project is Schiphol's fire brigade. In order to innovate the fire brigade, it is important to get to know the firefighting world as best as possible. Therefore a user centered design approach (ISO, 2010) is combined with a design driven innovation method (Verganti, 2009). This implies the use of context mapping, observations, interviews with firefighters and a culture analysis to analyze the context. Next to that a vision for the future is created based on the visions of key influencers in the firefighting market. These influencers have a clear view of what is happening in the market and where the opportunities are.

Based on the outcome of these two methods together and an analysis of the emerging technologies several design directions are extracted. One design direction is chosen and developed into a final concept. The final concept is validated by making a proof of concept and through interviews and user tests. The proof of concept is a model showing the usage and interaction of the product and a prototype that shows the technical functionality of the product.

Structure

Figure 1 shows the structure of the project as described in this report. The first chapter explains the context and the firefighting culture. In the second chapter the future vision is developed using the design driven innovation method and an analysis of the technology. The third chapter describes how to improve the fire brigade, making it more efficient and safer. Here the needs of the firefighters are analyzed. It results in the final design direction namely, the health of the firefighter. The fourth chapter focuses on the design direction in more depth, by analyzing the factors which influence the health of the firefighters. Chapter five defines the final concept, The QuantiFire system. In chapter seven the concept is validated on its feasibility for development at the fire brigade and the value it brings. This results in the recommendations. The last chapter summarizes the key results of the whole project, the consequences of the concept and the next steps for continuing the development.

Reading guide

Each chapter is built up in the same way. It starts with an introduction to the chapter followed by the explanation of the that is used in used in that chapter. At the end of each chapter, a conclusion provides a short summary including the obtained key insights.

Rectangular blocks are used to indicate the importance of the information. The different colors mean:

Interesting information

Key insights of the chapter

More in depth information


Source: own photo

1. UNDERSTANDING THE CONTEXT

1. **Approach**
2. **Firefighting at Schiphol**
3. **Implementation**
4. **Efficiency and safety**
5. **Case studies**
6. **Conclusion**

In order to create a vision that would help in developing the fire department, it is important to know what firefighting at Schiphol comprises, how it is organized and how it is developing. This chapter describes the organization and culture of the fire department of Schiphol and how to implement new innovative products. This helps to understand the context of the project and gives insights for the analysis for implementing innovation.

Approach

Information for an analysis of the firefighting at Schiphol is obtained on the basis of literature, on observations at the fire brigade and on conversations with employees from Schiphol. The analysis will include, what it means to be a company fire department, how the fire brigade is organized, what the facilities and locations of the fire brigade are, the tasks and activities firefighters do during the day, the equipment they use and the developments that took place in previous years.

For the implementation of new products it is important to understand the culture and learn from mistakes made in the past. The culture of the Schiphol fire department is analyzed using the Competing Values Framework by Quinn en Rohrbaugh (1983). This results in advantages and disadvantages of the firefighter culture. Besides that, a case study for several projects at the fire department is done in order to learn why these projects failed or succeeded.

At Schiphol the firetruck should be at any place on the runways within three minutes in normal conditions.

Firefighting at Schiphol

Company fire department

The Schiphol fire department is a company fire brigade. Companies can be obliged to have a fire department when there is an increased risk of fire and accidents (Wet veiligheidsregio's, 2010), for example, when hazardous materials or large amounts of flammable materials are used. Schiphol is according to the International Civil Aviation Oranisation (ICAO) a category 10 Airport. This is the highest category based on the size, the traffic and size of aircrafts (Brandweer Amsterdam Airport Schiphol, 2016). This requires a certain firefighting capability; at Schiphol the firetruck should be anywhere on the runways within three minutes in normal conditions. The airport also requires an alarm centre (AC). The AC at Schiphol is in direct contact with the air traffic control tower.

A company fire brigade must meet the same requirements as the government fire brigade, but the fire officer is appointed by and accountable to the company (IFV, 2016). The fire brigade of Schiphol operates mainly in the Schiphol area, meaning all buildings, roads (also the public roads) and fields. All emergency services in the Netherlands are divided over 25 safety regions. In these regions there is a co-operation between the boards and services in the fields of fire services, disaster and crisis management, medical care, public order and safety. The fire department of Schiphol is officially part of the Kennemerland safety region. Therefore they can also assist the regional fire brigades in the areas around Schiphol if required.

Tasks and Activities

The five main tasks of the firefighters are: pro-action (eliminating structural causes of insecurity), prevention (all measures to prevent fire outbreaks), preparation (all preparations for a repression such as exercises and training, maintenance of equipment and deploymentplanning for special objects), repression (all activities in order to control, suppress and to prevent expansion of a fire, accidents or disasters as quickly as possible) and after-care (prepare for a new alarm, staff care, reporting and PR) (IFV, 2016).

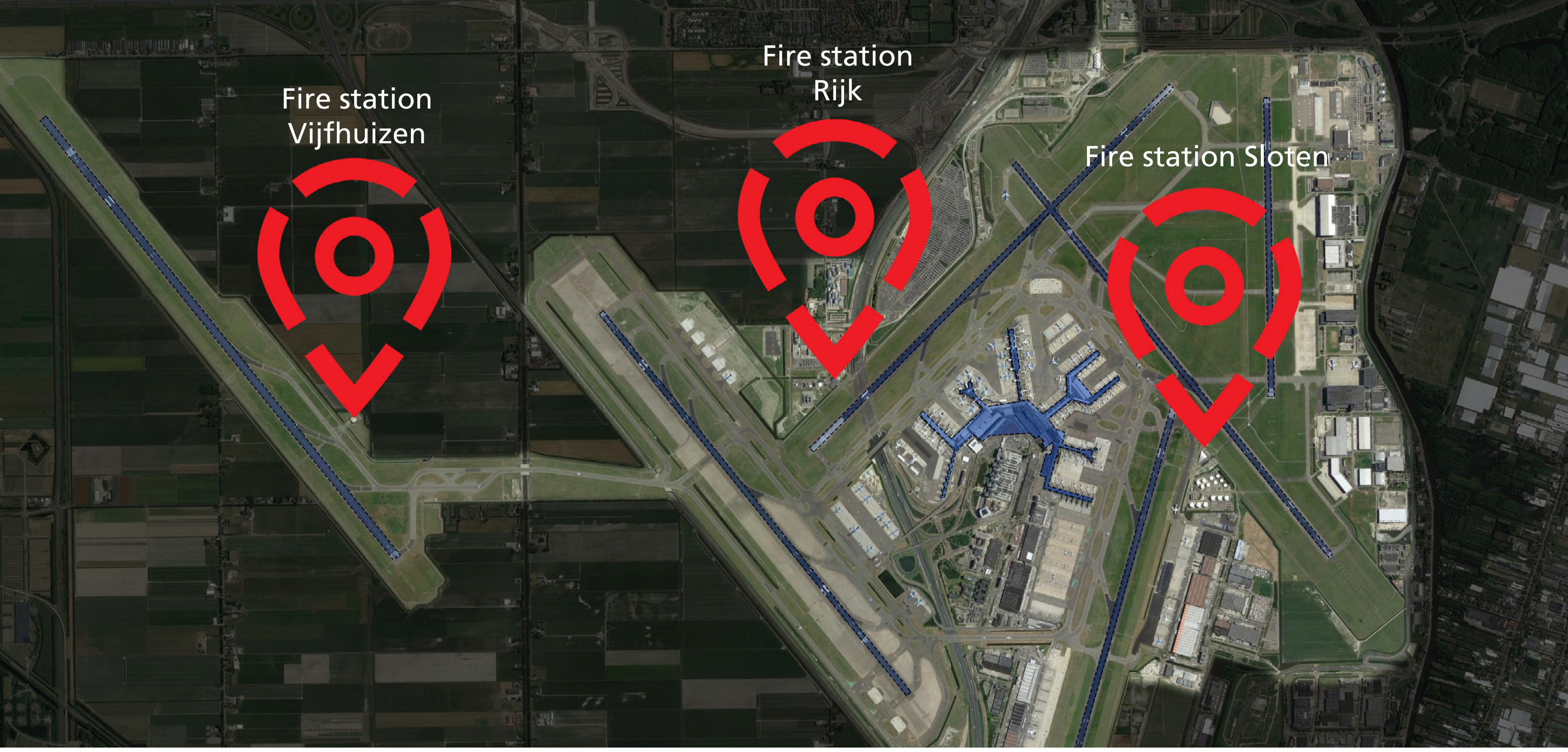


Figure 2. Map of Schiphol with the three fire stations. Source: Google Earth

At Schiphol the emergency units are divided in two different units:
› Aircraft firefighting unit
› Building firefighting unit

The difference between these two are the vehicles they use and the deployment technique.
For aircraft firefighting, the first step is to make sure that everybody inside the plane survives by extinguishing the fire and by controlling the ventilation. If the firefighters would start with saving the passengers, they will only be able to save a few, the rest will not survive due to suffocation or incineration.
Building firefighting on the other hand is focused on saving victims first. When there is no danger for a person, they would start with extinguishing the fire or let it burn out controlled.

A unit always consists of 6 persons.
Building firefighting units consists of: a commander, a driver/pump operator, an assault squat (2 persons) and a water team (two persons). They are all in one firetruck, see figure 3.
Aircraft firefighting units consists of: a commander and 5 firefighters. They operate three crashtenders in total with two persons per crashtender. Every fire station has three crashtenders to their disposal. Crashteders are specially designed firetrucks for aircraft firefighting.

Fire stations

There are three fire stations situated in the Schiphol area, to be sure every runway can be reached within the three minutes requirement. The three fire stations are, station Sloten, station Rijk and station Vijfhuizen, see figure 2. Sloten is the main station, meaning it is the biggest, and has office and training facilities. The fire stations are occupied 24 hours per day by professional firefighter units. They work in shifts from 8:00 in the morning until 8:00 the next day.

Firefighting equipment

To protect themselves from the harsh conditions, firefighters need to wear personal protective equipment. This equipment protect them from fire, heat, toxic gasses, injuries, and helps them to perform the job as good and as quickly as possible. The basic equipment is shown in figure 4.

Schiphol fire brigade is covered by the Public Procurement Law, this means that they have put out a tender for their work, services and supplies. Therefore the suppliers change from time to time (±10 years). The main suppliers for Schiphol at the moment are Dräger, MSA.

A day of a firefighter

As mentioned before, a work shift begins at 8:00 in the morning and takes 24 hours. It starts with a meeting for changing the shift. During this meeting, important information will be exchanged. The rest of the day will be spent on maintenance of the equipment and vehicles, condition training (one hour every day) and firefighting training and exercise. At the night they sleep at the fire station.

Firefighting training and practices vary from fire drills in occupied buildings and offices to fire

Figure 3. Training aircraft at Schiphol fire station Sloten. Red vehicle on the left is a Crashtender for aircraft firefighting, on the right is a firetruck for building firefighting. Source: Own photo

Figure 4. Personal protective equipment of a firefighter. Source: Composition

Figure 5. Ian Downing receiving innovation of the year award fom CEO Jos Nijhuis. Souce: Schiphol Group

extinguishing technique training in a container and exploring the terminal buildings. The main training facility is located near fire station Sloten. At the training facility all possible situations can be simulated. It also contains the iconic training aircraft: the FireFly (figure 3)

Developments

Schiphol's Fire department is a private company. Therefore commericial interest is important and the company wants accidents prevented or solved as quickly and with the least amount of casualties as possible, for the image of the company and to assure it does not delay the running business of Schiphol. That is why there is a budget for developments and innovation, in contrast to the national fire brigade. In recent years, the Schiphol fire department have run a few innovation projects. But most of these projects have never been deployed. Mostly because they run into some technical or political problems or because the project period had ended. A more detailed analysis will be given later in this chapter.

FFor the rest of Schiphol Group, innovation has become more important as well. They see the world of aviation changing quicker than before, and therefore the innovation department Schiphol NeXt has been established. NeXt is doing research on developments and future technologies, and is examining what this means for the future of Schiphol. NeXt also tries to stimulate other employees to be more innovative. This attitude is put into practice for all departments of Schiphol and NeXt wants to stimulate employees from the fire department to be more open for new developments. Firefighters are now joining innovation bootcamps organized by NeXt. Even the first innovation of the year award (an initiative of NeXt) went to firefighter commander Ian Downing, because he worked on a lot of innovative projects in 2016.

Schiphol NeXt is working with students, interns and graduation students. In September 2016, a multidisciplinary team of students from the Windesheim University of Applied Sciences, started a project with the fire department. This project runs parallel with this graduation project. They developed a device that makes it possible for firefighters to track their location by only using digital motion sensors. This will be described in more detail later this chapter, together with some other case studies.

The Kennemerland safety region, could also initiate new developments. Currently, they are implementing the Mobile Operating Information system (MOI system). This system is developed to help firefighters to quickly and clearly get all the necessary information about an emergency. In addition, the MOI system also provides an optimal collective image during an incident. The system runs on all platforms and could be used on the tablet of the commander (Kennis Informatieplatform Hulpverlening, 2016).

It can be said that the fire department of Schiphol is working hard to keep up with new developments. But what kind of developments are really important? How can the fire department of Schiphol be prepared for the future? The next chapter will investigate how the future of firefighting will look like through interviews with market influencers and experts. Schiphol could be an example for the nationwide fire departments or airport firefighters around the world.

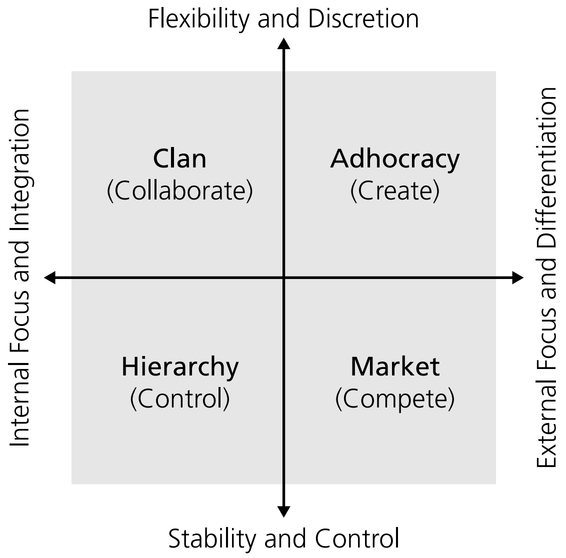


Figure 6. The Competing Values Framework by Quinn and Rohrbaugh (1983)

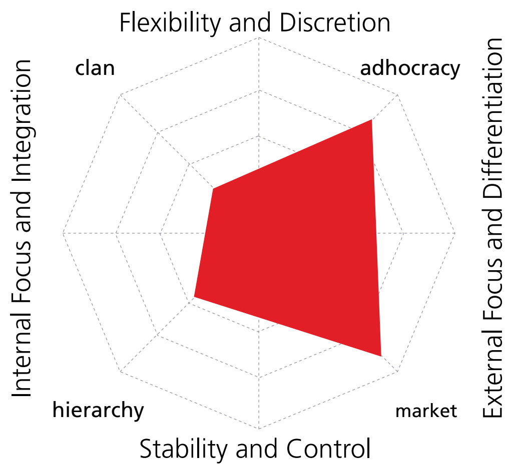


Figure 7. Results from the online OCAI tool filled in by the fire department. Source: OCAI online

Implementation

Culture

'They are on their own island.' That is often the view within Schiphol about the fire department. Their main station Sloten is located on the other site of the A5 highway, far away from the terminal and Schiphol's headquarter. As a result, there is not much exchange between the employees at Schiphol headquarters and the firefighters at Schiphol. Also the firefighters developed their own culture. This could be due to the geographical distance between both groups, but it could also be due to the type of people and the work that they do. The culture could have positive and/or negative effects on the process of implementing new innovations, therefore it is important to make an assessment of the culture.

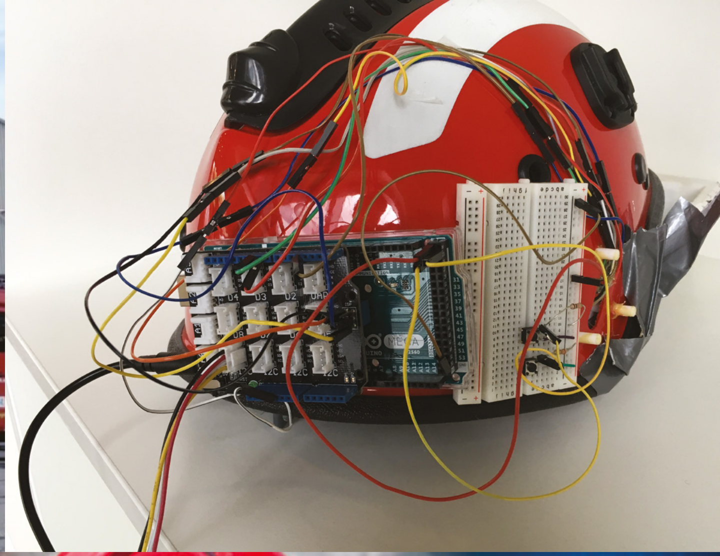
To make an assessment of the organizational culture, various models have been developed by researchers. The dominant framework in literature is the Competing Values Framework by Quinn & Rohrbaugh (1983). This framework identifies an organizational culture in four different culture types: people-oriented (The Clan Culture), result Oriented (The Market Culture), Focused management (The Hierarchy Culture), innovation-Oriented (The Adhocracy Culture). These culture types correspond to four competing values: Internal focus & integration vs. External focus & differentiation and Stability and control vs. Flexibility and discretion, see figure 6. Based on this framework is the Organizational Culture Assessment Instrument (OCAI) by Cameron & Quinn (2005). OCAI helps to identify the current culture of an organization in the form of a survey.

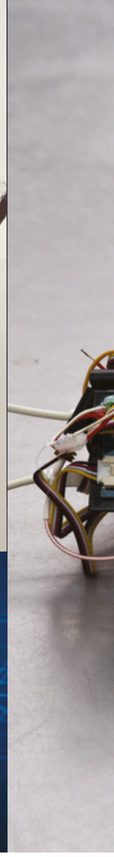
The assessment of the Schiphol fire department culture is made using the online OCAI tool (OCAI online, n.d.). According to the results, shown in figure 7, the culture can be seen as people-orientated and a focused management and to a lesser degree as results and innovation orientated. Meaning it is a sociable and structured work environment. Teamwork is important and it feels like one big family, there is a high commitment participation and loyalty. There are strict rules and procedures and the ranks and functions are clear.
In the framework from Cameron & Quinn (2005), these culture types are expressed in an 'internal focused' and a slightly more 'stable and controlled' culture. Their orientation is focused internally instead of interacting or competing with external parties and they are a little more effective when they are stable and predictable instead of in changing.

From this assessment a few advantages and disadvantages for implementing new innovations can be extracted:

Disadvantages:
- Rigidity - Making changes in their work and in procedures is difficult.
- Strictness - New implementations are subjected to these rules.
- Internal focus - They like to solve their own problems, instead of collaborating with other parties.

Advantages:
- Concern - When a new implementation offers advantages to the people or the team, it will be embraced quicker.
- Hierarchy - There is a high commitment when things are instructed from the higher ranks.
- Supportive - There is a strong will to support others.





Efficiency and safety

The main question of this project is how to make firefighting more efficient and safe by implementing smart technology. Therefore we have to look at what efficiency and safety mean at the fire department.

Chapter two and three will investigate the needs firefighters have about safety and efficiency and the technology that can enable improvements.

Efficiency:
To make firefighting more efficient, there are three components that can be improved:

- Making the job easier - New technology makes it possible for firefighters to do their job quicker and better. For example better extinguishing techniques or better communication devices.
- Efficient use of the resources - To use the resources in the most efficient way, it is necessary to know where, when and how it can be used to ensure its full potential is used.
- Reduce costs - Reducing the costs can be split into two On one side there is the costs of the organization, the employees and the material. On the other side cost reductions can be made by limiting the damage. Especially at Schiphol, the cost of the damage adds up quickly.

Safety:
The three safety components that can be improved are:

- Prevent injuries of the firefighters - Firefighters get into dangerous situations. That is their profession. They are trained to work under extreme conditions and their equipment is designed to protect them from harm. Still, there is a big risk for the mental and physical health of the firefighters that can be improved.
- Prevent victims - Firefighter's first job is to save people from dangerous situations. Improved methods to save people or prevent them from harm makes firefighting as a whole more safe.
- Fire prevention - Over the years, the type of fire that occurs has changed. Due to the use of more plastics and other new materials in buildings and products, fires became more aggressive. The fire scales up faster and it produces more toxic gasses. Preventing fires from happening or reducing the dangerousness of the fires is a way to make firefighting more safe as well.

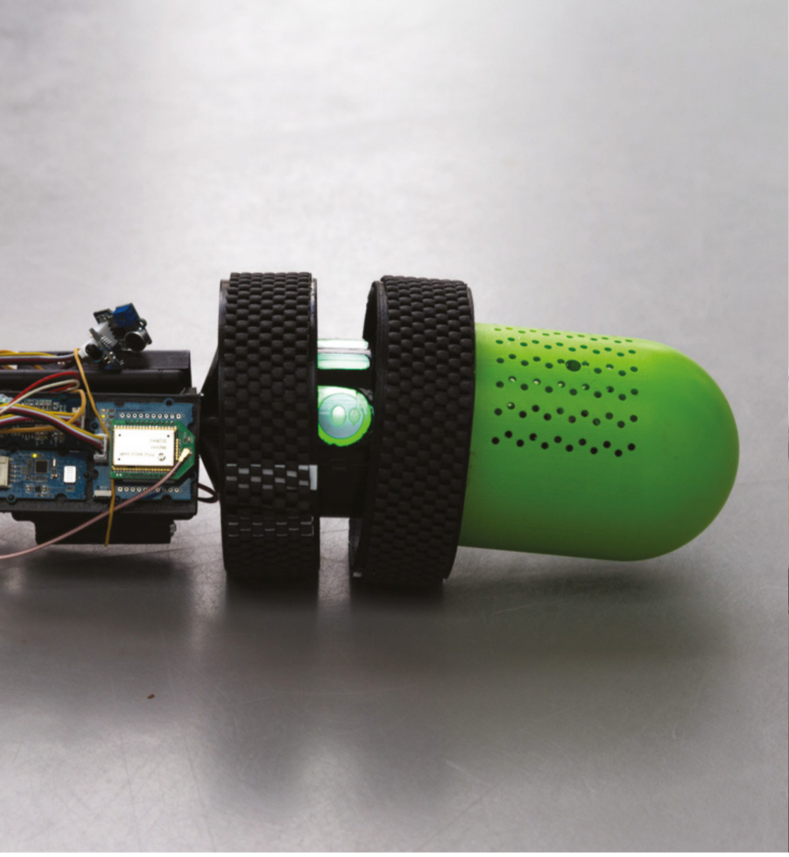


Figure 8. Case study projects, from left to right: MoSeS, Smart@Fire, First Step, AMI and Radar project

Case studies

Previous projects show what can go well or wrong when implementing new innovations at the fire department. Figure 8 shows a few projects that are performed the Schiphol Fire Department and other fire or emergency departments in the past. These Projects are described in appendix 1. The First Step project performed by student from the Windesheim University, as mentioned before, is described in this chapter.

First step

As mentioned before, the First Step project, runs in parallel with this graduation project and had the same goal as this graduation project: creating a smart product that makes firefighting more safe and efficient. However the approach differs: while this graduation incorporated a user centered design approach, the First Step project took the agile approach, Scrum. Therefore the design direction was chosen early on in the process in order to quickly start prototyping and make iterations. The chosen direction was a device that would show the way back to the exit when firefighters are inside a building without the use of GPS.

Wikipedia definition:

"Scrum is an iterative and incremental agile software development framework for managing product development. It defines "a flexible, holistic product development strategy where a development team works as a unit to reach a common goal", challenges assumptions of the "traditional, sequential approach" to product development, and enables teams to self-organize by encouraging physical co-location or close online collaboration of all team members, as well as daily face-to-face communication among all team members and disciplines involved."

The result is a prototype that tracks the users walking route by using motion sensors only. The fire department of Schiphol reacted positive to the result. A device that could enable this would be useful. However, the prototype build was still in a primitive state, it could recognise the direction of a persons step and show this on a display, but it could not show the route back. Besides, the possible direction was only left right and strait forward, anything in between would not be recognised. Therefore a lot of development should still be invested in how the product should be used and in the technology aspect.

Although the results are promising, the fire department has difficulties to continue with the project after it has finished. According to the supervisor of the project, the students didn't include a clear roadmap on how to continue with the development of this product. It was not clear which partners should be incorporated and which steps should be followed.

Learnings:
- When testing a concept with the fire department it is important to communicate clearly what the goals of these tests are. The fire department can lose trust in the project when they test different concepts that all fail.
- Technical problems could cause a project to fail
- It is important to tackle a small problem instead of solving a total and complex problem. In this way, it is easier to implement it and not lost the trust of the fire department.
- A lot of projects are carried out by students in a limited time frame. It is important to make someone responsible for implementing the project after the students are gone and provide a clear roadmap for future developments.
- A project could fail when it becomes too expensive and doesn't generates revenues. This is especially true at the fire department, which only costs money. Therefore it is important to have a clear business case for the project.

In chapter 8, in the project results, the final concept will be reflected on these learnings.

Conclusion

Concluding from the analysis of Schiphol's fire department, it is possible to state that innovation in firefighting is necessary for Schiphol. The fire department has the duty to keep the business running and resolve issues as quickly as possible. The fire department is covered by the Public Procurement Law, therefore all work, services and supplies need to go through the tender process. The fire brigade of Schiphol has two different types of firefighting: building firefighting and aircraft firefighting. Both of these types need different equipment and procedures. In general the firefighting department tries to eliminate structural causes of insecurity, it takes all kinds of measures to prevent fire outbreaks, it prepares for an emergency by training, maintaining equipment and by making deployment plans. When a fire does happen, the fire department perform all activities to reduce the number of victims and the amount of building damage. The firefighters work in shifts of 24 hour, they sleep at the fire stations and work always as a unit. The units consist of 6 persons including the commander.

The culture of the Schiphol fire department is rigid, strict and has an internal focus. This makes it difficult to make changes in the procedures and habits except when this change is coming from themselves. On the other hand employees of the fire department are concerned with each other, there is a strong hierarchy and there is a strong will to support each other. Therefore all developments that adds value and is a benefit for the people or the team will have more success.

To make the fire department more efficient and safer, it is important to make the job easier, use the resources more efficient by reducing costs and by preventing injuries, victims and the emergence of fire.

It is difficult to implement new innovations at the fire department. Therefore it is important to work closely with the firefighters to really understand the problems they have. It is important to start on a small scale, test a lot and implement in small steps. The next two chapters will investigate what needs firefighters have.

Key insights:
- Take small steps at the time
- Involve the firefighters during the process
- Ensure an innovation adds value to the people or the team

Source: own photo


Source: own photo

2. THE FUTURE OF FIREFIGHTING

1. Approach
2. Enabling technology
3. Design driven innovation
4. Interpreting: A future vision
5. SWOT
6. Conclusion

In this chapter, a vision of how firefighting will look like in the future will be constructed. Therefore the emerging technologies are used as a basis together with the visions and statements of industry leaders. This results in strengths, weaknesses, opportunities and threats for innovation at the fire brigade.

Approach

Before analyzing smart technologies the term smart technology has to be defined. Then the emerging technologies are collected from the research and advisory firm Gartner (Gartner Inc., n.d.). These technologies are used for making future firefighting scenarios.
The design driven innovation method is used to construct a future vision based on the perspective of experts in the field of firefighting.
Finally a SWOT analysis is used to combine the insights of this chapter and the previous chapter.

Enabling technology

Smart technology

Definition by Zoughbi & Al-Nasrawi (2015):

Smart technologies are the technologies (includes physical and logical applications in all formats) that are capable to adapt automatically and modify behavior to fit environment, senses things with technology sensors, this providing data to analyze and infer from, drawing conclusions from rules. It also is capable of learning that is using experience to improve performance, anticipating, thinking and reasoning about what to do next, with the ability to self-generate and self-sustain.

In short, this means applying artificial intelligence to input and take some actions. The term applies most to electronic devices that are connected to the internet and can be used interactively. Because of this broad definition, most emerging technologies are smart technology or are enablers for smart applications.

Emerging technology

Research and consultancy firm Gartner publishes a prediction for emerging technologies every year. They visualize this in the Gartner's Hype Cycle (Walker, Burton, & Cantara, 2016).

For the analysis, the hype cycles of emerging technologies between 2013 and 2017 are used. These technologies in combination with technologies from other sources, are combined on technology cards. These cards are clustered resulting in future scenarios, see figure 9.

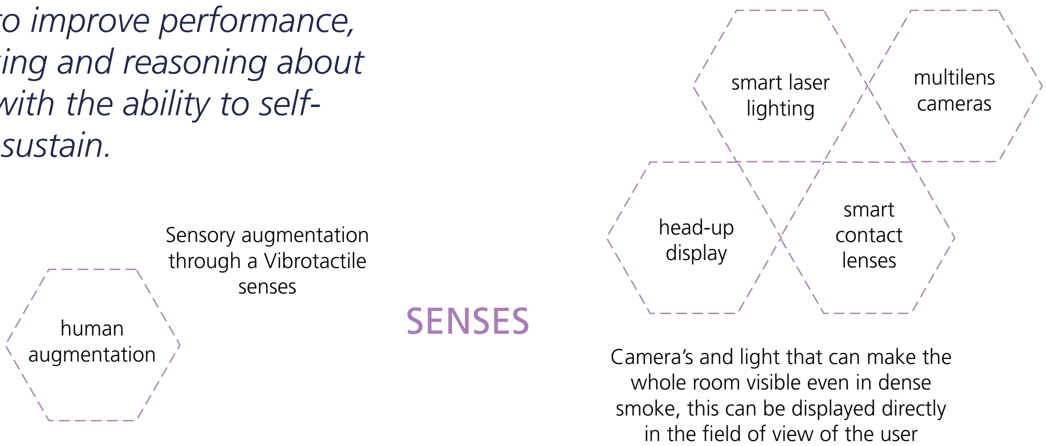


Figure 8. Technology clusters with future scenarios

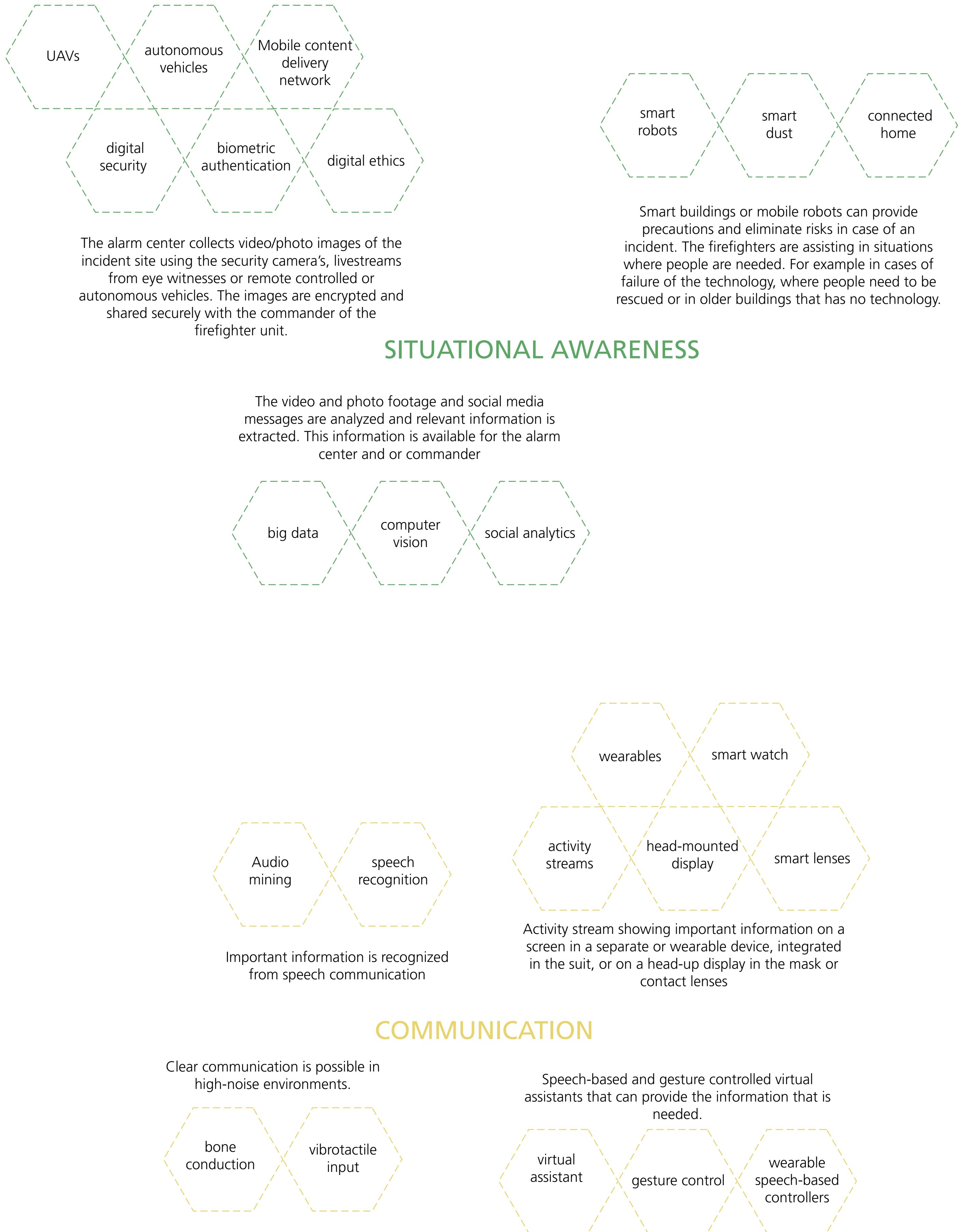


Figure 9. Technology clusters with future scenarios

wearables
head-up display
holographic displays
volumetric displays
smart lenses
augmented reality
smart watch

Digital (3D) maps of the buildings and navigation routes are available on a screen in a separate or wearable device, integrated in the suit, or on a head-up display in the mask or contact lenses

indoor location tracking
NFC
mesh networks:
IoT platform
personal trackers

The location of all people can be seen on the map

NAVIGATION

Relevant information on the map or in augmented reality is shown only when needed or can be switch on or off by hand

Information is stored on the device, but it is constantly updated with the latest information

hybrid cloud computing

personalization engines
gaze control
brain computer interface
bioacoustics sensing

smart data discovery
mobile personal emergency response system
gamification

Advise and challenges for improvements are shown and a doctor can be called automatically

exosceleton

Heavy physical work is illuminated by the use of an exoskeleton

PHYSICAL AND MENTAL HEALTH

Mental and physical health status is constantly tracked and visualized on a personal device

smart garments
smart footwear
personal analytics
perspiration analysis patch
gait analytics
electronic wristband
impact monitors
emotion recognition/ detection
sports watches
skin bio patch

Body temperature can be controlled with cooling elements in the suit

smart garmets

Design driven innovation

According to Verganti (2009), a user-centered design approach doesn't allows radical innovations to happen which could change the meaning of a product or service. He proposes the Design-Driven Innovation philosophy that innovates by collaborating with key interpreters who are attuned to the culture and the specific business contexts, see figure 10. These key interpreters conduct research on how people give meaning to products and services and they develop things that influence these meanings. Interpreters can be artists, engineers, academics, designers, students, or practitioners; in general they act as industry influencers.

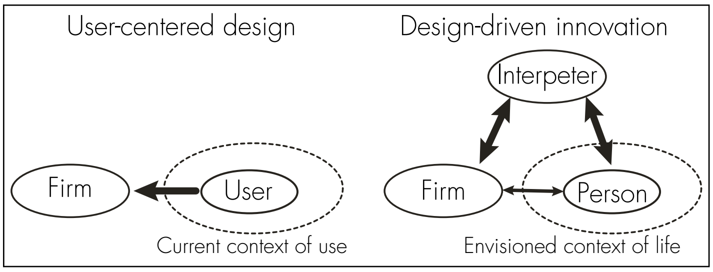


Figure 10. User-centered design versus design-driven innovation, Verganti (2009).

The process of design-driven innovation has three actions (figure 11):

1. **Listening**. Gaining knowledge about possible new product relevancy from the interpreters.
2. **Interpreting**. Generating your own vision and proposal for significant meaning.
3. **Addressing**. Discussing and comparing your vision with the interpreters. The interpreters on will then try to influence the user on how they give meaning to a certain product.

Action three is out of the scope of this graduation project, due to the term and scale of the project. But it will be an important part for the next steps after this project. The intended user of this project is an employee of the company that is developing the product. That is why the first two actions are combined with a more user-centered design approach, which will be described in the next chapter. This enables a design based on the needs

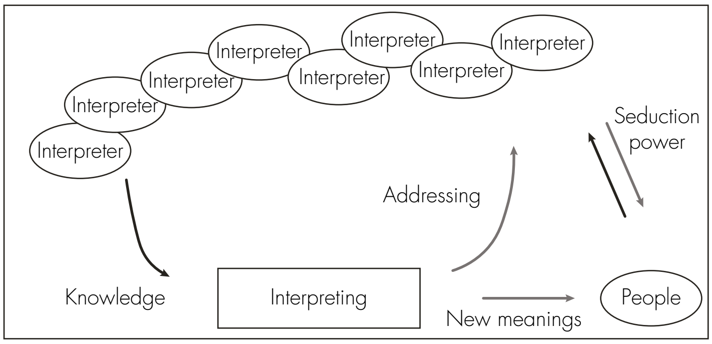


FIgure 11. Process of design-driven innovation, Verganti (2009).

of the user (adding direct value for the firefighters) and on a long term vision for the future (adds value over time for the whole organisation).

A total of five interpreters were found:
› Pieter van Gelder - Professor of Safety and Security Science and Director of the TU Delft Safety and Security Institute
› Peter Butter - Fire of cer and Innovation manager at Brandweer Amsterdam-Amstelland
› Arthur Haasbroek - Senior Planvormer, Operational Preparation at Brandweer Hollands Midden and active at iNowIT: national innovation platform for emergency services on the eld of information
› Eric Mol - Researcher at IFV (physical security institute)
› Patrick van Vugt - Business Unit Manager VT at Dräger

They are all working on innovation for the firefighting industry. They have distinct ideas of how the future of firefighting should look like. An interview was preformed with all of them in which they could expressed their vision and statements and how they think the role of the firefighter will change in the future and which technology will play an important role.

Pieter van Gelder

Professor of Safety and Security Science and Director of the TU Delft Safety and Security Institute

Van Gelder predicts a shift in the fire services from a repressive task to a more preventive task. Firefighters will raise awareness about fire hazards among people, perform checks of buildings and objects and make safety regulations for buildings.

Due to better prevention techniques, fires will occur less, but there will always be a human factor. People make mistakes and that can result in a fire. A complete elimination of a fire will never happen.

Technologies that will play an important role according to Van Gelder are:

› Camera implementations (bodycams, on vehicles, on drones, etc.) This will broaden the field of view to a new perspectives and from new locations. Drones reach locations quickly, because they can fly in a straight line.
› Controllable and self-driving extinguishers This will guarantee the safety of the firefighters because there is no physical risk for the driver.
› Fire-resistant coatings This can prevent a fire from happening.

Peter Butter

Fire officer and Innovation manager at Brandweer Amsterdam-Amstelland

Butter thinks the future of firefighting is in the information flow. The right information should be available for the right person at the right time. Firefighters and especially the commander needs a lot of information. Most of this information is available at the moment of alarm, making them overloaded with information. The information should be phased.
Another option is using technology to extent the human capacity: Neurofitness. There are some pilots with this technology. It help the process larger amounts of information.

Butter also sees a change in the roll of firefighters, it is moving them to the front by going from door to door and we visiting large company buildings. Firefighters gets a more social function. This is because fires occur less, but due to the use of different materials, they are more dangerous. That makes us more cautious than before. If there is no danger for people we will try to use a cobra or extinguishing robot.

Arthur Haasbroek

Senior Planvormer, Operational Preparation at Brandweer Hollands Midden and active at iNowIT: national innovation platform for emergency services on the field of information.

For Haasbroek ‘data’ is the most important factor for the future of firefighting. He envisions a firefighting organization that generates data from all possible activities. For example, the amount of incidents, the locations, the size and what causes the incident but also how the deployment is performed, what is communicated, etc.

He describes the benefits of using data in three components:
- Smart organization based on data analyses
- Prove achievements with data
- An excellent information flow

In a smart organization, data can be used to analyze for example the most efficient location and size of the fire stations, the number and location of the fire hydrants and the required call-out times. Also it could help to prevent incidents by analyzing the causes of incidents. Precautions can be made based on this data. This could lead to a more efficient organization with lower costs.

This, also will reduce the amount of firefighting work, or at least the visible work with clear results. Like Van Gelder and Butter said, their work will change to more preventive activities. This makes it more difficult to ascertain the results. How do you show you prevented an incident? This is an important aspect because of the financial picture. But data can also be used as to prove the achievements. Data analytics can prove correlations between firefighters precautions and the reduction of incidents.Data analytics can prove correlations between firefighters precautions and the reduction of incidents.

According to Haasbroek fire departments need a well organized back office to manage the information flow. This back office, is in close contact with the firefighters in the field and has an overview of the situation. They can use all resources available (data analytics, camera footage, building maps, etc.) to support the firefighters in their decisions and provide them with the necessary information. In the long run, a lot of the processes done by the back office could be automated.

In a stressful situation, administration activities are the first that are skipped. That is why gathering data should be automated. For making good use of the data, all data is needed.
Also, there is a great resistance of fire departments to gather data. It can harm the privacy of the employees and it will lead to changes in their work. The firefighter culture is protective. They don’t want you to change their work, because making it more efficient will result in less work. They don’t have this mindset because competition is not what they want. This is important to keep in mind for the implementation. New innovations should be introduced with small steps and the people should be included in the process.

“Privacy is a great thing for us all, but if you deliver craftsmanship, people want to know who this craftsman is. An artist signs his works as well.”

On the privacy issue, Haasbroek comments:

Eric Mol

Researcher at IFV (physical security institute).

Eric Mol refers to the bow-tie model from the safety science, see figure 12. This model shows the incident (fire) as the node. The left side of the node are the measures taken to prevent the incident from happening. The right side shows the measures taken to limit the impact when the prevention measures failed and the fire occurs. According to Mol, the current safety chain focusses especially on the right side of the model. Due to new building and furniture materials and better isolation, fires are more toxic, hotter and takes more time to be visible from the outside. Therefore the changes for survival are lower, for both civilians and first responders. Investments in measures for limiting the effects will therefore have less effect on the amount of damage and the number of victims. Measures taken to prevent the fire from happening will limit the number of fires and therefore have a positive effect on the amount of damage and victims. The book Brandweer Over Morgen (Projectteam Strategische Reis Brandweer, 2010) explains the new doctrine:

"firefighters promotes fire safety awareness and personal responsibility"

The node in the bow-tie model shifts towards the right side. The the repression of the fire will still be the responsibility of the fire brigade, the left side, fire prevention, will be the responsibility of the whole society, while the firefighter will have an advising or coordinating role.

This will have a large effect on the work of a firefighter, according to Mol. Considerations needs to made how to perform a deployment, which could mean working with less people and, not entering the building etc. Therefore the firefighter get new responsibilities and fire brigades need to reconsider the hiring criteria. Fire prevention also means being well prepared for a repression of the fire. This means, equip firefighters with the necessary means but also ensuring their health is guaranteed.

Mol, who is specialized in the health of firefighters, puts a high values on the advantages of monitoring firefighters during training and deployments. This helps them to know their limits and can help limiting the casualties. Next to health, Mol values technologies that improve the situational awareness, like drones, security camera's etc.

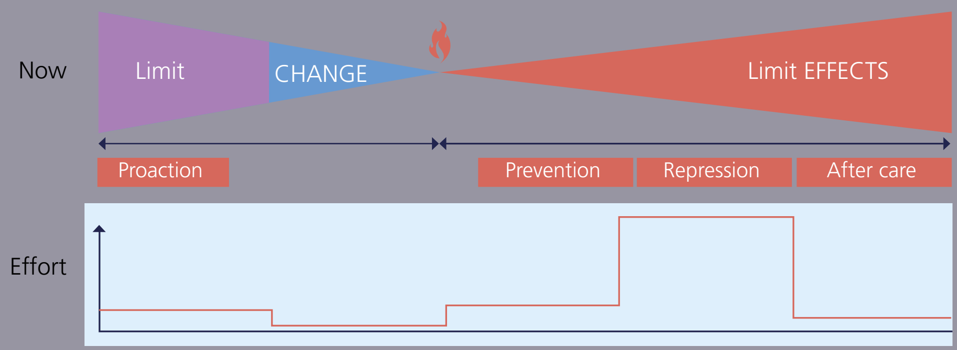


Figure 12. Bow-tie model from the safery science.
Source: De brandweer over moren (2010)

Patrick van Vugt
Business Unit Manager VT at Dräger.

Van Vugt, looking from the perspective of Dräger, recognizes the statements of the others that the focus of firefighting is shifting towards fire prevention. He notices that especially in the number of specialized groups. In the past every fire station had his own diving team or teams with chemical protection suits. Now there are only a few of these teams in the Netherlands. But these teams are more specialized and trained, therefore they need more specialized equipment as well. For Dräger, innovation should be focused on these groups.

Interpreting: A future vision

Looking at the insights gained in chapter one and the visions of the experts, certain resemblances are occuring.

The role will shift to a more defensive task. Repression of the fire will never be excluded completely but it will decrease dramatically. Therefore changes are necessary in the way the firefighter works. Automation will also enable the firefighter to stay away from danger.
Data analytics plays an important role in the future of firefighting, enabling it to organize the fire department in a more efficient and safe way. Fire departments today are not used to gather data, therefore a number of small steps needs to be made. This could be done by providing short term values with the collected data. The long term values will come automatically.

More attention will be given to the safety of personnel. Firefighters take risks in order to save other people's live, but the fire brigades duty is to make the risks as low as possible.

"A ship is most safe in the harbor, but it is not designed to stay in the harbor."
Eric Mol

The same applies for firefighters, they are most safest when they are at the fire station, but that is not their job. Therefore firefighters should be trained and equipped for all possible deployments.

Firefighters work as cohesive teams. They should use this strength to perform the deployment as good as possible. This also implies in making decisions. At this moment, the commander (or fire officer in case of large fires) is the only one making important decisions. Of course they incorporate the opinions of his crew in the final decision, but he is the one responsible. This responsibility could be shared by using technology. When the fire department assigned one commander to stay at the back office, he could support the commander on location. He could have access to all the digital available support and is not charged with the hectic of the situation. This could eventually even be taken over by artificial intelligence. According to Teerlink (2017), in five years, artificial intelligence will be used for all important decisions made in people's life.

Strengths	Weaknesses
Positive effect on the business (both on financial profits and on the brand image) Advantage for the employees or the team Makes firefighting more efficient Makes firefighting more safe	Need to have versus nice to have Changes firefighters work or procedures Dependency on technology Complex projects lose trust quickly
Opportunities	**Threats**
Shift towards the front of the safety chain Automation Data analytics Safety of the personnel	Technology failure Specialized groups

Figure 13. SWOT analysis of the firefighter's culture

SWOT
An SWOT analysis is used to map out the strengths, weaknesses, opportunities and threats in the current culture and their developments. These results will be used in the next chapter as criteria to choose the final design direction.

Conclusion
The field of firefighting is changing. All experts in the field agree on that. Where extinguishing fire was the main task in the past, now it is more and more shifting towards fire prevention. This will change the role of a firefighter and maybe even the type of person that will be hired as a firefighter. A fire department will benefit in the investment of data analytics, this could contribute to a more efficient firefighting organization. Therefore a shift in the attitude of firefighters is needed as well. Now privacy issues are still a barrier for this to happen. Therefore it is necessary to take small steps and add short term value.
Other developments that are important for fire brigades are: automation, health monitoring technology, the use of a back office, and visualization methodology.

Key insights:
- Fire brigades are shifting towards more fire prevention tasks
- The role of the firefighter will change.
- Data analytics could play an important role in making firefighting more efficient
- Automation can make firefighting more safe
- Health monitoring could help the firefighters in training
- A back office could help dividing responsibilities for important decisions


Source: own photo

Communication:

- Normal communication is difficult with the oxygen mask
- In case of multiple teams, there is an information overload, making it difficult to extract important information
- The hectic situation, sometimes makes you forget to communicate important information
- It is difficult to communicate your location
- It is difficult to understand the other person in the radio

Assessment:

- The information and the distribution of it is always different
- It is not possible to know the situation until you see it
- Nine out of ten times, the situation is different then what was thought of beforehand
- Everyone makes a different assessment of the situation

Health:

- Making use of after care, feels like being a patient, this is an obstacle for most people
- The signals from the body when the core temperature is too high, are difficult to recognize
- The physical health is tested a lot, but the mental health isn't
- In order to recognize toxic materials easy, we often use the nose

Navigation:

- The maps of the buildings contain too much information
- Sometimes, you have to find your way by touch
- You forget the way back
- Driving when it is foggy, is difficult
- There are a lot of procedures for driving on the runway

Equipment:

- You cannot fully make use of your senses when wearing your suit
- It is difficult to recognize other people in dense smoke

Figure 14. Problem statements resulting the context mapping analysis

3. A SAFER AND MORE EFFICIENT FIRE BRIGADE

1. **Approach**
2. **Context mapping**
3. **Information journey map**
4. **Design directions**
5. **Direction choice**
6. **Design goal and interaction vision**
7. **Conclusion**

This chapter identifies the needs firefighters have in their work. What kind of innovation do they need? The answer is determined through a context mapping analysis. These needs combined with the results of the previous chapters will be converted to opportunities. From the opportunities, one design direction is chosen to continue with in this project.

Approach

Context mapping is an approach to gain valuable insights for innovation by involving the user as the 'expert based on his or her experience' (Visser, Stappers, van der Lugt, & Sanders, 2005). It is a set of tools in order to map out the context in which the intended product or service is used. In the case of this project, the context can be defined as all the daily work related activities of the firefighters. This is the context in which the new innovation should be used. The analysis consisted of three parts; observation, a sensitizing booklet and a creative session.

The outcome of this analysis is plotted on an Information Journey Map. This results in the design directions. The final design direction is chosen with the support of a new product profile. A new product profile, or Harris Profile, helps evaluating the directions on a set of criteria (Harris, 1961). Finally a design goal and interaction vision are created that are the basis of the rest of the project.

Context mapping

Observation

The observation was conducted during a 24-hour service that was followed at the building fire unit of fire station Sloten. These observations are used as insights for the information journey later described.

Sensitising booklet

Two weeks prior to the creative session, all participant where asked to fill in the booklet during a 24-hours service 2. The main goal of this exercise is to help the participants to observe and reflect their daily activities. This prepared them for the creative session. On a timeline they had to fill in all they activities done during their work and they had to indicate whether the activity went efficiently or not and whether it was safe or not.

Creative session

Seven firefighters and two other employees from Schiphol participated in the creative session. During this session, the firefighters got the chance to express their (negative) experiences during their work and think of future scenarios 3. The session was divided in three parts:

- A brainstorm session with the whole group about the participant's experiences and problems on the basis of a number of themes (these themes are based on the outcome of previous chapters).
- Individual ideation sessions for solutions of the most important problems
- Making a future vision in groups

After the session results of the first part, a rich amount of Post Its with problem definitions and quotes, are clustered. The most important problems are shown in figure 14.

The clusters will be used to create the design directions:

- Communication
- Assessment
- Health
- Navigation
- Equipment

Information journey map

To identify which information is needed at what time an information journey map is created. On this journey map all information that is currently lacking or is not distributed is indicated.

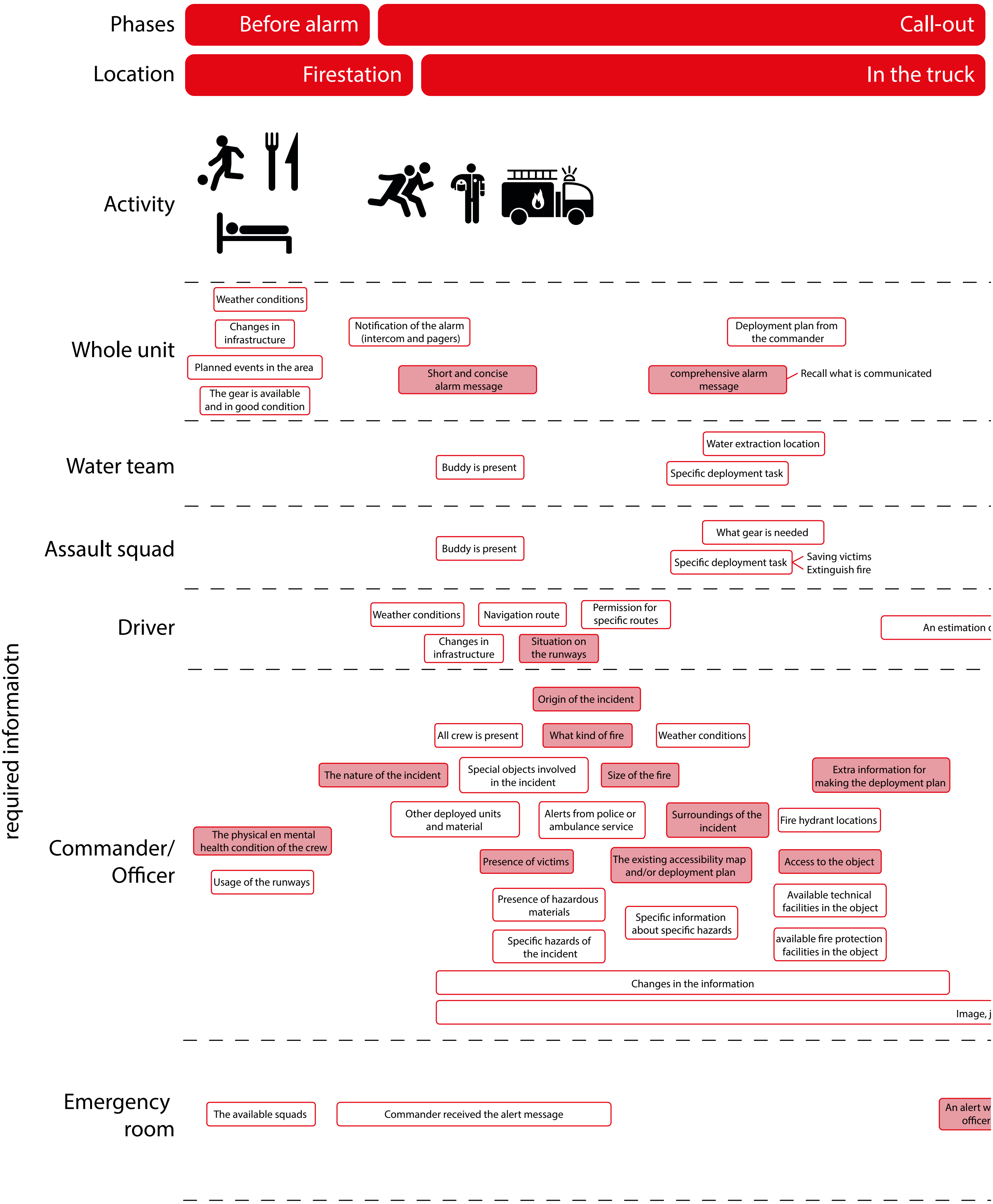
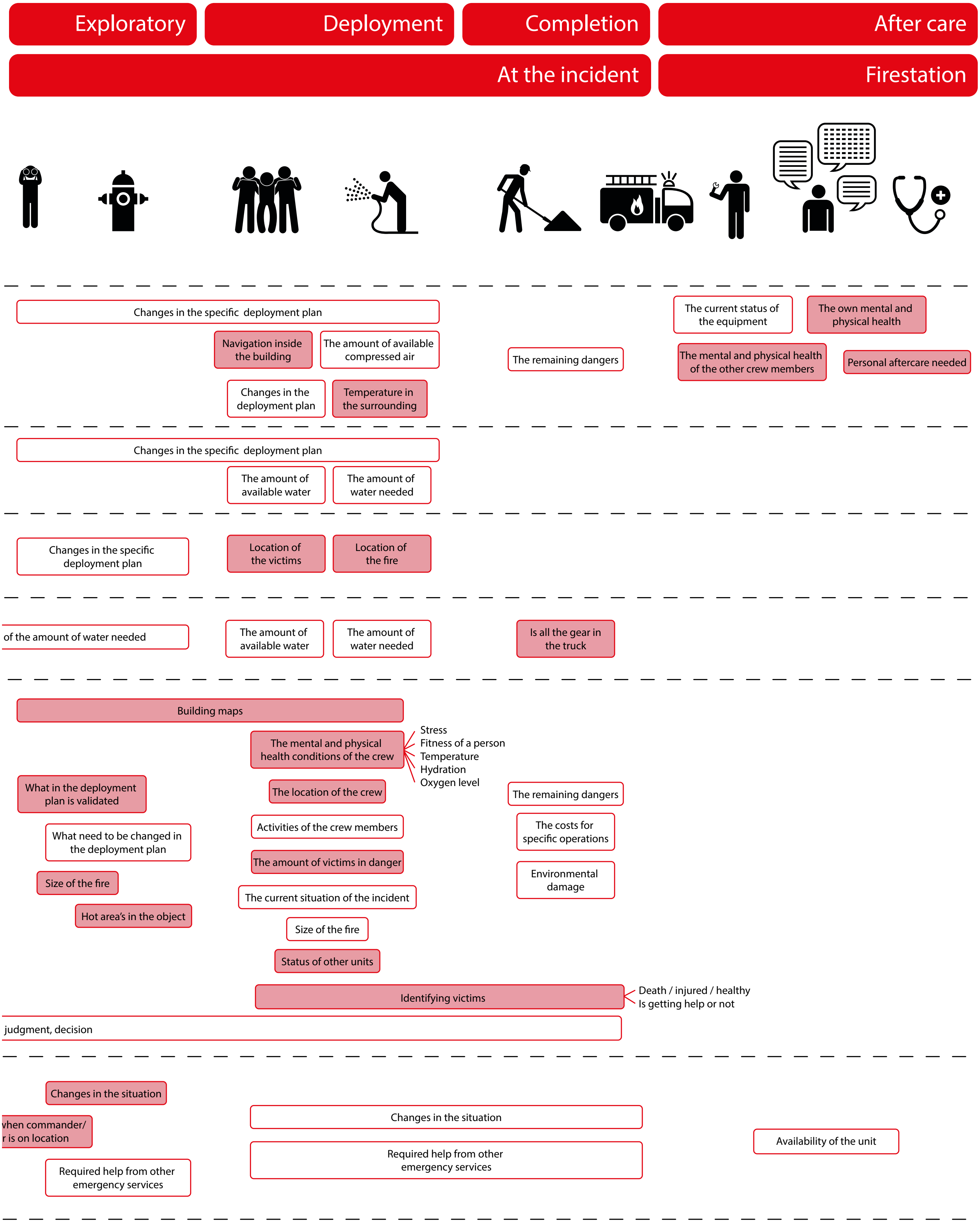


Figure 15. Information Journey Map



Design directions

The five clusters from the contextmapping analysis form the basis for the five design directions of this project.

A possible scenario is made for the four directions: artificial senses, virtual situational awareness, easy navigation, monitoring health.

<u>Smart communication</u>

During an operation firefighters have to communicate a lot over the radio. The radio doesn't always work well, it is difficult to understand each other and if you use earphones, it makes it more difficult to communicate directly. Also, it requires a lot of attention and concentration and it is hard to keep track of what is communicated. Some parts of the communication could be automated or displayed in a visual way.

<u>Artificial senses</u>

During an operation a firefighter cannot fully use his senses. Sight is limited due to dense smoke, feeling is difficult with the suit and the use of smell is dangerous in case of hazardous substances. Using the senses is the most effective way for people to measure certain things. Artificial and intuitive sensors could help to cope with the loss of the senses.

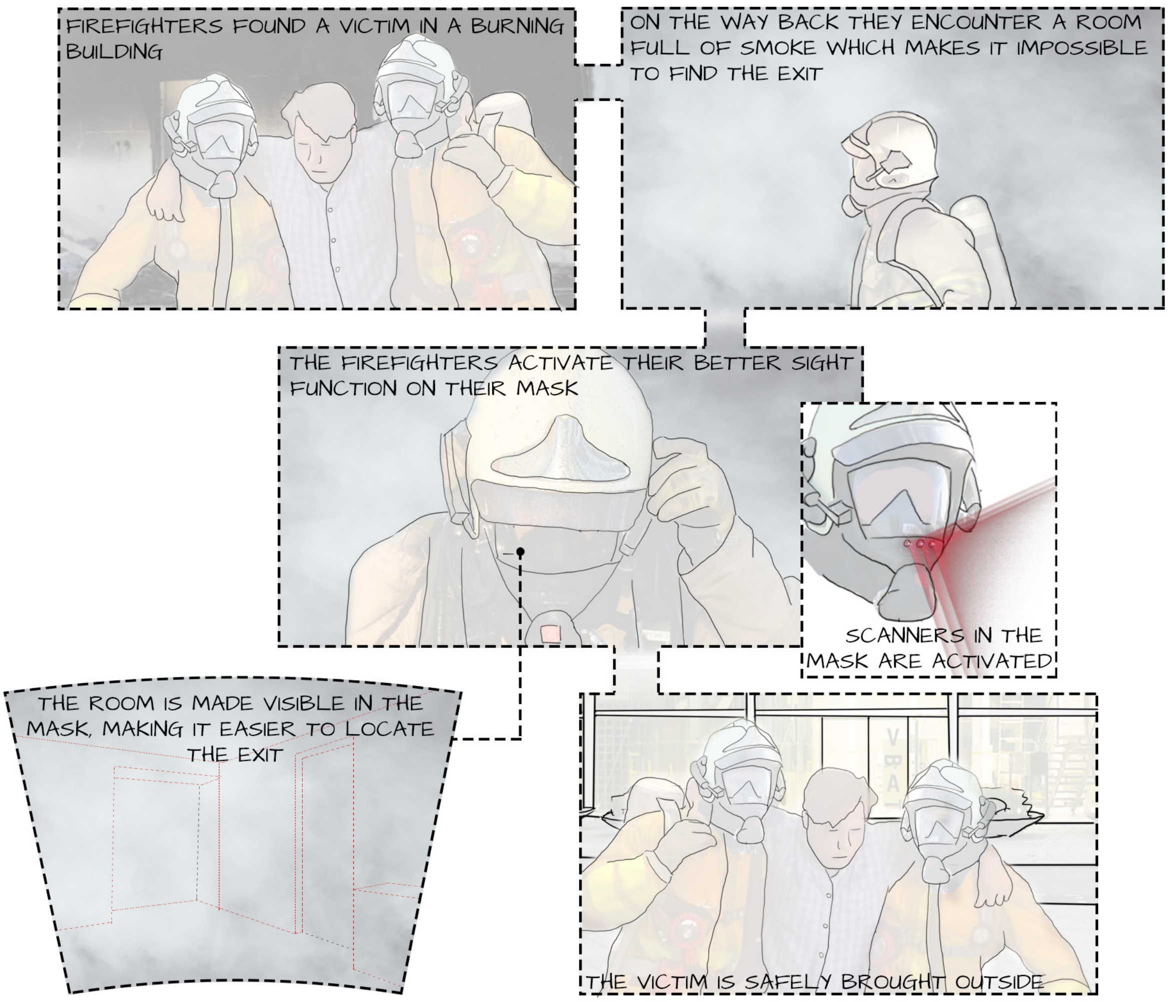


Figure 16. Possible scenario for the artificial senses direction

Virtual situational awareness

Till the moment of arrival on location, it is hard for firefighters to get a good picture of the situation. This makes it impossible to make a good deployment plan. At Schiphol, almost every location is covered by security cameras and almost everybody has a smartphone with camera. These images could help the firefighters to make an assessment of the situation before arrival. The firefighters need a platform where they can find all necessary information about the incident and the status of the deployment.

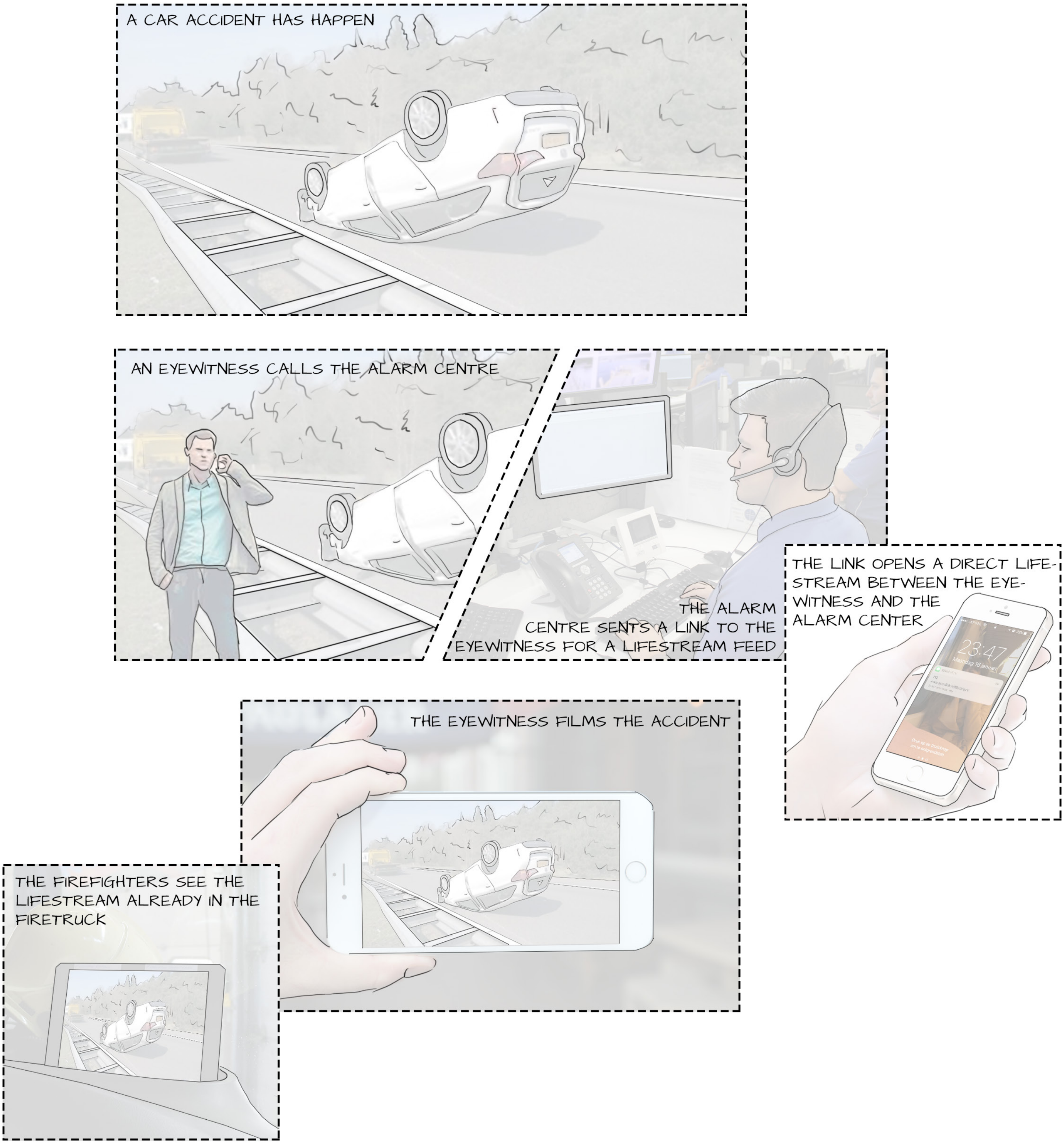


Figure 17. Possible scenario for the virtual situational awareness direction

Easy navigation

Easy navigation inside complex buildings at Schiphol and being able to see where everybody is located, is a strong need of the firefighters. The paper maps, used today contain too much information and are therefore confusing. A solution is a digital map that shows the information you need at that moment and the location of all crew members.

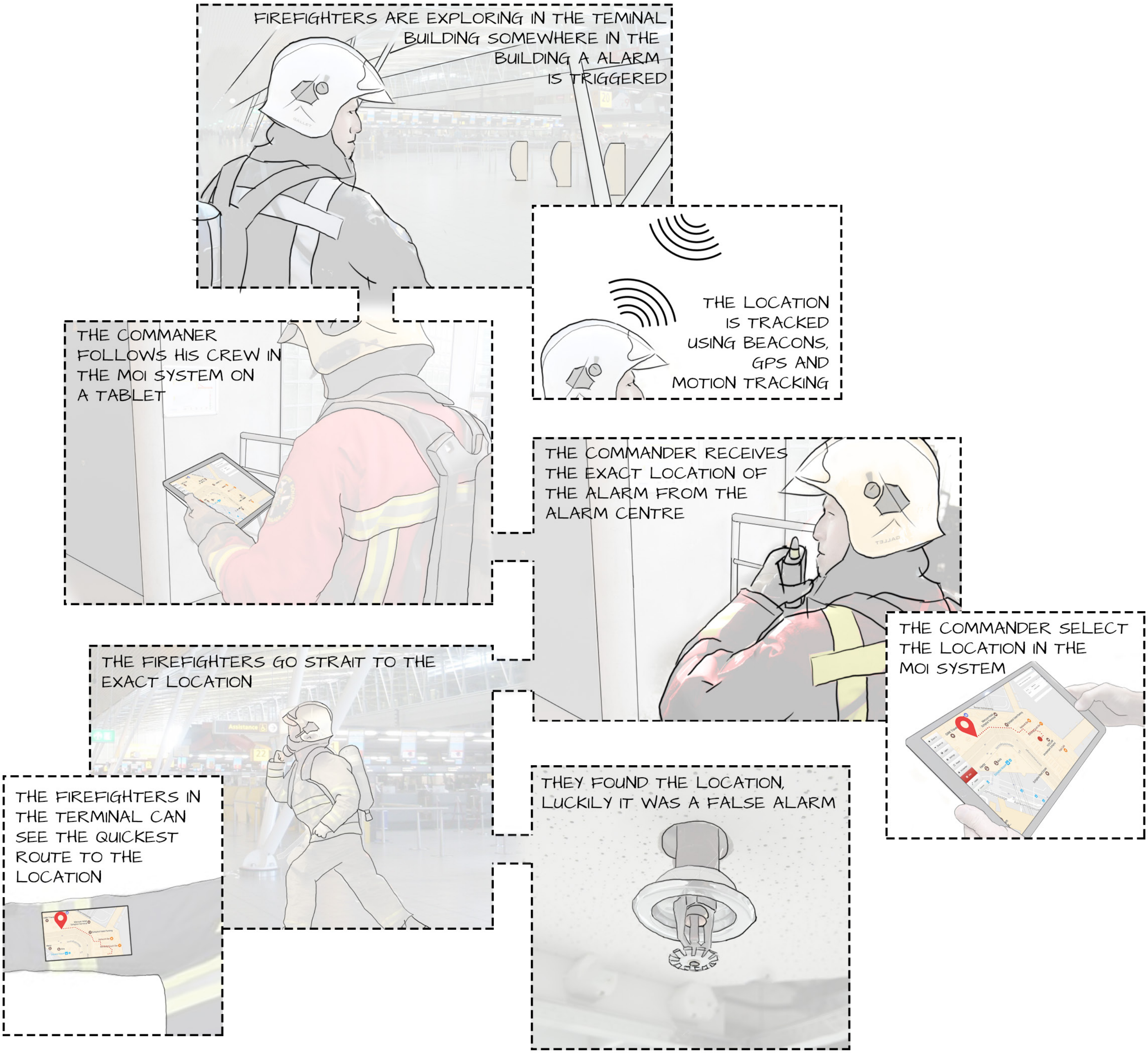


Figure 18. Possible scenario for the easy navigation direction

Monitoring health

A firefighters deploy ability is strongly influenced by his medical condition. Not only the current environmental situation a firefighter is facing influences the medical condition but also sleep, taking alcohol, sporting, having problems at home can reduce the overall physical fitness. A firefighter is trained to recognize the indicators that tells him his health is at risk, but this is easy to ignore during hectic situations or it could mean it is already too late. Also it is socially less acceptable to come across as weak and having to ask for help. When the symptoms are recognized using technology, it could take away the human factor of ignoring and it could help to break through the social blockade. Measuring the physical and mental health status of the firefighters could help recognizing the early symptoms of physiological injuries and could provide information on how to prevent these injuries.

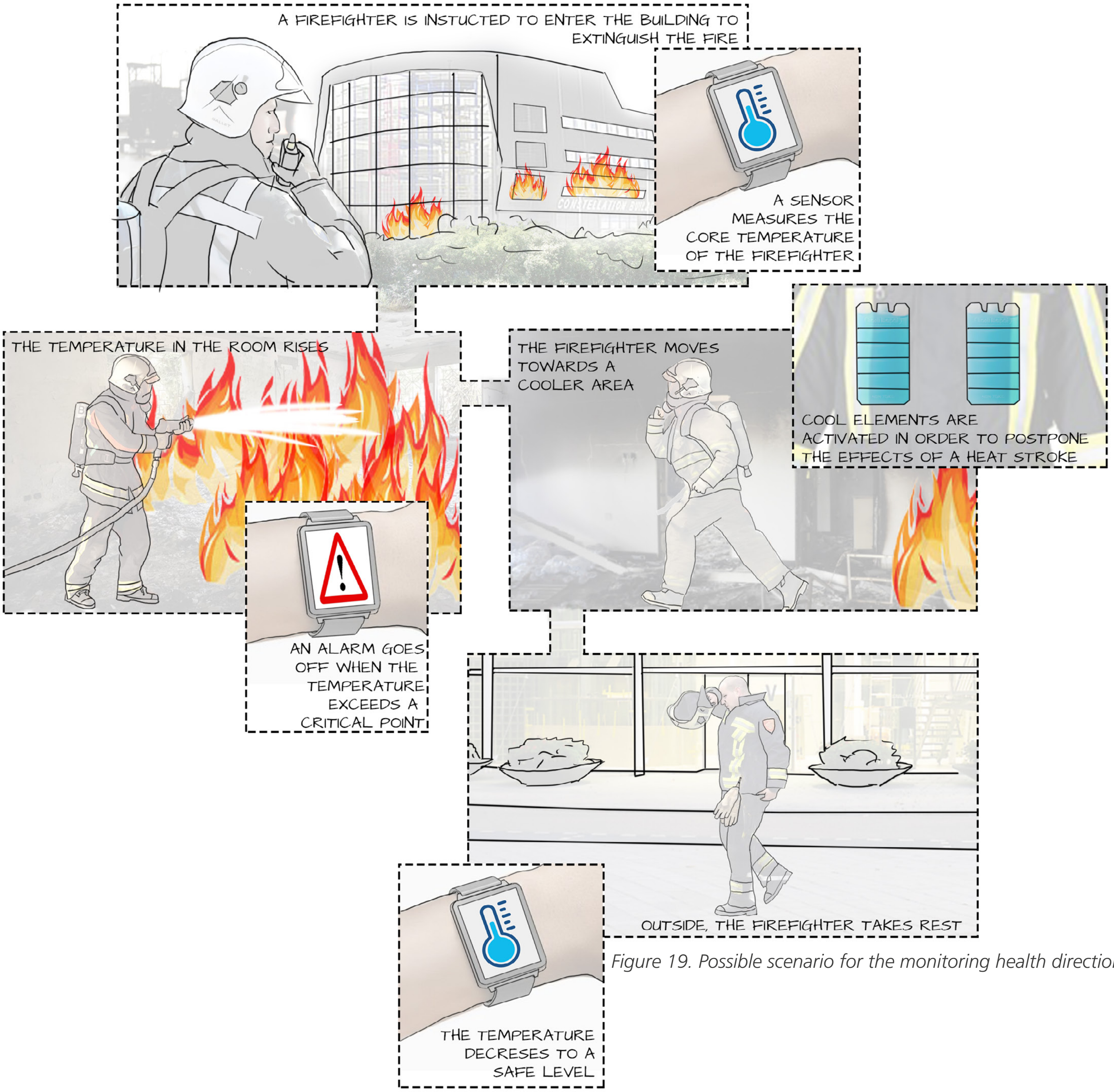


Figure 19. Possible scenario for the monitoring health direction

Direction choice

The five directions have different potential for the fire brigade, Schiphol and the graduation project. These factors together with the SWOT analysis from the chapter two are the criteria on which the directions are compared in the new product profile (figure 20). This profile provides a basis for the decision for the design direction.

The "assessment" and "communication" design directions have, compared to the other directions the best potential for both the fire department and Schiphol as a private company. It solves a common problem that the company is facing at the moment. The others are more based on opportunities than a problem, making it less interesting for the company. On the other hand, the two directions "assessment" and "communication" are less interesting for the graduation project because the problems need less innovative solutions than the other directions. "Location tracking", "Health" and "Senses" are all new directions for the fire brigade, therefore a more innovative solution is possible.

"Communication" and "Health" score best on the SWOT analysis. "Communication" because it best eliminates the weaknesses and "Health" because it fit the opportunities the best.

The health direction is the most interesting direction to continue with. It has great potential to make a start with gathering data for data analytics and can benefit to make firefighting a more safe profession. In the next chapter, we will look at what aspects of the health of a firefighters are important to keep track off and why this direction can be combined with the 'communication' direction.

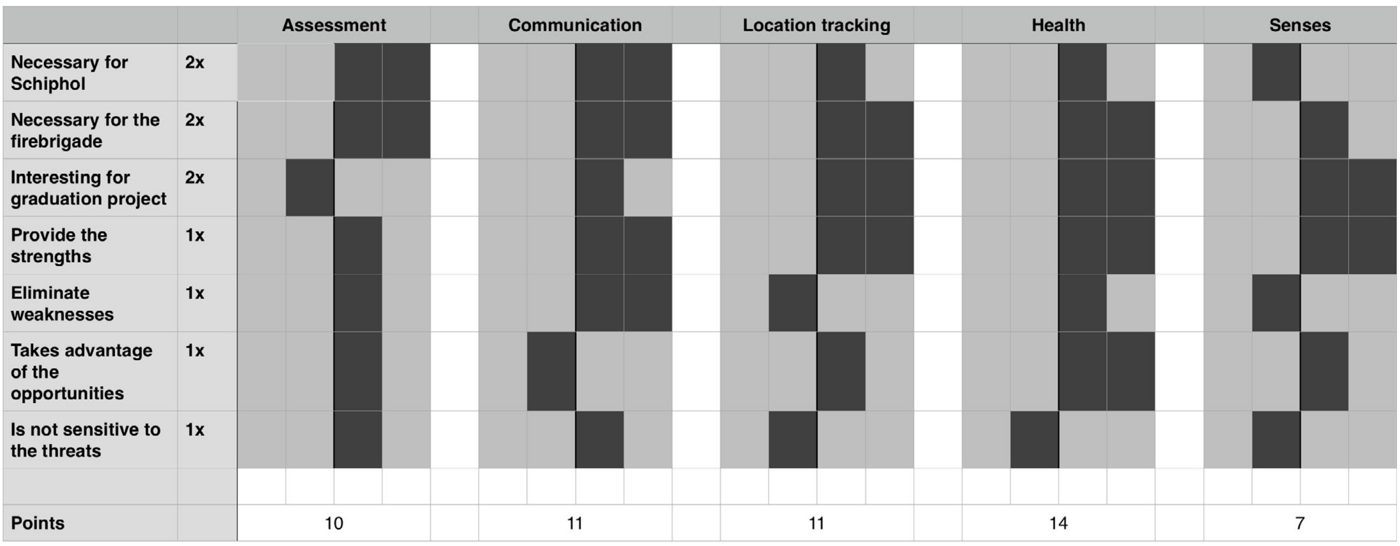


Figure 20. New product profile for selecting the design direction

Figure 21. Interaction vision: a high wire walker. Source: NY Times

Design goal and interaction vision

Design goal
Make a start with collecting data at the fire brigade by enabling the firefighters to keep track of they body conditions during physical activities. By doing so, it enables them to make the right decisions for their health at the right time.

Interaction vision
A firefighter voluntarily steps into a dangerous situation. In this situation he needs to control his body in order to survive. If the balance inside the body is disturbed, it could cause serious danger. The device should provide insights into this balance. The interaction of the product will be like the pole of a high wire walker: This pole helps him to notice every little factor that is influencing his balance in the vulnerable situation.

Conclusion
The context mapping analysis resulted in five important clusters of problems: Communication problems during deployment, the lack of information to make an assessment, the difficulty to monitor the health of the firefighters, the problems with navigation in the complex buildings of Schiphol and the problems caused by the protective equipment. This resulted in five similar design directions: Smart communication, virtual situational awareness, health monitoring, easy navigation and artificial senses. The health monitoring direction is chosen as most promising, this direction has the potential to make a more efficient and safe firefighting brigade.
The design goal is making a device that enables health monitoring and provide data for efficiency analysis. The interaction with the device should be like the pole of a high wire walker.

Key results
- Final design direction is ‘health monitoring’
- The design goal is: making a device that enables health monitoring and provide data for efficiency
- The interaction mataphor is: the stick of a high wire walker

Source: Jaromír Chalabala

4. THE FIREFIGHTERS' HEALTH

Firefighters are generally very fit people. They do lots of exercise and sports during their work. This is necessary to perform their job in the most optimal way when they have a call out; they even compare themselves with athletes. But the circumstances firefighters are facing are quite dangerous and could cause a lot of bodily harm. It is not enough to train for these circumstances, you need to learn how to deal with it. This chapter describes important elements of the health of a firefighter and how to keep track of it. It concludes with a decision that leads to the final concept, a smart earpiece. A storyboard investigates the possibility of this smart earpiece.

Approach

The health aspects of the firefighter is analyzed by looking at the activities that influence their health and deployability. Then the factors that could be monitored with technology, are analyzed. Heat stress is the factor that is chosen to focus on in this project and researched in more detail using literature and interviews with experts. This leads to the concept of a smart earpiece. In a storyboard the usage of the earpiece is analyzed. The final concept will be elaborated in the next chapter.

"In the USA physiological injuries, and especially heart attacks, are the leading cause of deaths among firefighters."

The health of a firefighter

It is well known that firefighting is a dangerous job with an excessive workload. They are facing life-threatening dangers as burning injuries, asphyxiation, getting stuck with no way out, explosions, collapses, hazardous materials, etc. Apart from these environmental dangers, even more threatening are the physiological effects of the heavy workload, such as heart attacks, strokes and even cancer (Smith, Liebig, Steward, & Fehling, 2010). In their work they have to move from a sudden stop and then to accelerate in heavy duress. Furthermore, the time, intensity and number of call-outs are unpredictable. In the USA physiological injuries, and especially heart attacks, are the leading cause of deaths among firefighters see figure 23.

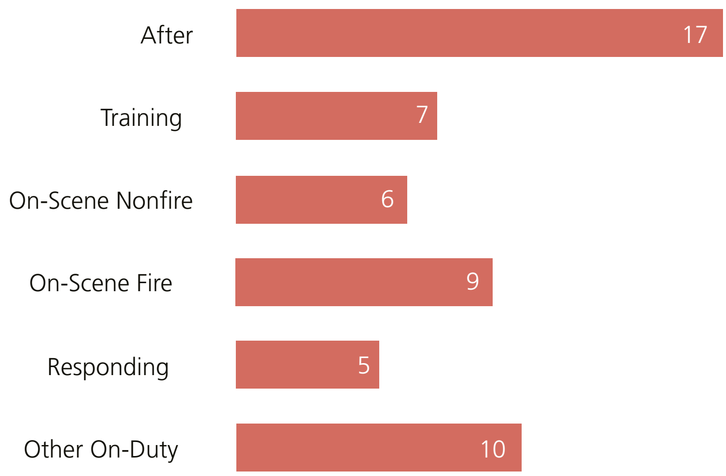


Figure 22.Heart attack by type of duty in the us (2015)
Source: Smith et al. (2010), editted

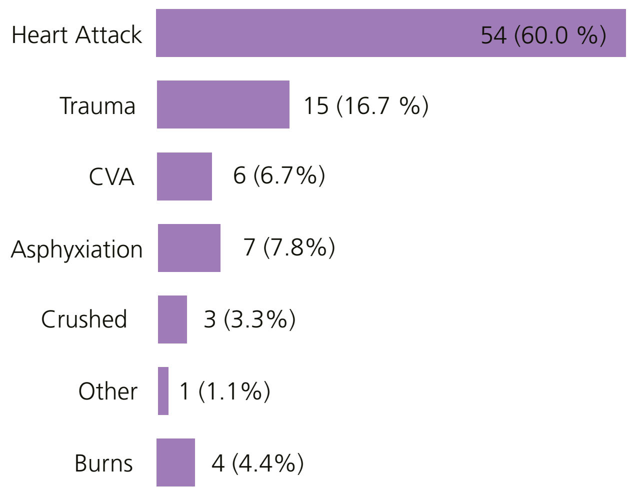


Figure 23. Fatalities by nature of fatal injury in the US (2015)
Source: Smith et al. (2010), editted

- **Cardiovascular** (Increased HR and BP, Decreased Stroke Volume)

- **Hematological** (Decreased Plasma Volume, Hemoconcentration)

- **Thermoregulatory** (Elevated Core Temperature, Dehydration)

- **Respiratory** (Increased Breathing Rate and Oxygen Consumption)

- **Metabolic** (High Oxygen Cost, Increased Lactate, Fatigue)

- **Immune/Endocrine** (Increased Leujocytes and Hormones)

- **Nervous** (Sympathetic Surge and Increased Adrenaline)

- **Muscular** (Increased Oxygen Use and Heat Production)

Figure 24. The physiological effects of firefighting on the different systems of the body. Source: Smith et al. (2010)

The firefighter statistics in the Netherlands are more difficult to find. However, according the NBDC, (2015) (The national firefighting documentation center) the fatalities of on-duty firefighters from 2010 till 2015 where all cardiac related but did not include fatalities which occurred in their spare time, but were related to their work as a firefighter. As seen in figure 22 in the USA hearts occur mostly after work. According to Mol (2017) from IFV, the problems with cardiovascular complications are highly underestimated and he acknowledged that more measures needs to be taken to reduce this problem.

Cancer is another hot topic in the world of firefighting since several studies have shown that firefighters have a higher risk of cancer than other people. This leads to a new trend in the Dutch firefighting: Work safely (IFV, 2015). A lot of measures are taken by all the fire brigades in the Netherlands to reduce the chance of cancer (NOS, 2016).

Understanding the physiological effects of firefighting and how this is related to several medical complications, may provide insight in how to prevent these complications and to know the deployability of a firefighter in using technology.

In figure 24 the primary effects of firefighting on the body are shown. The strain on the cardiovascular and thermoregulatory systems are the most severe as it is responsible for heart attacks and strokes.

Cardiovascular strain is a result of strenuous firefighting activities and is enhanced by thermoregulatory strain and leads to cardiovascular deceases. (Smith, Liebig, Steward, & Fehling, 2010)

Thermoregulatory strain is a result of the combination of heat and strenuous firefighting activities. This results in an increase of the core temperature and dehydration (Smith, Liebig, Steward, & Fehling, 2010). When the body can no longer regulate the core temperature, it is called heat stress. Heat stress and dehydration together accelerates fatigue, reduces working hours, causes heat illnesses, strain, impairs cognitive ability and increases the risk of injuries as well as contributing to cardiovascular strain as mentioned before.

Because heat stress is a cause of both cardiovascular diseases and heat illnesses this project will focus on the heat stress only. But that does not mean it is good to include the cardiovascular stress and hydration in the future.

Influences on deployability

The variables necessary for making an assessment of the firefighters ability to be deployed are: heat stress, hydration, mental stress, energy level and lack of oxygen (Kerrigan & Moss 2016).

Heat stress

Measuring heat stress is important because it could have fatal results and causes a person to make wrong decisions, which may result in fatalities.

The following information is based on the book Human Thermal Environments by Ken Parsons (Parsons, 2002) unless indicated otherwise.

To perform optimally, the human body always strives for a heat balance, which is the core temperature of around 37˚C. As seen in figure 25, there are four environmental and two behavioral parameters that define the thermal environment of a person. Environmental: air temperature, radiant temperature, humidity and air movement. Behavioral: metabolic heat (heat gain) and clothing (a persons can decide to wear clothes or not). To obtain a stable core temperature the increase in metabolic and environmental heat gain should be equal to the heat loss. When the heat loss is not sufficient the body will store the heat and the core temperature will rise.

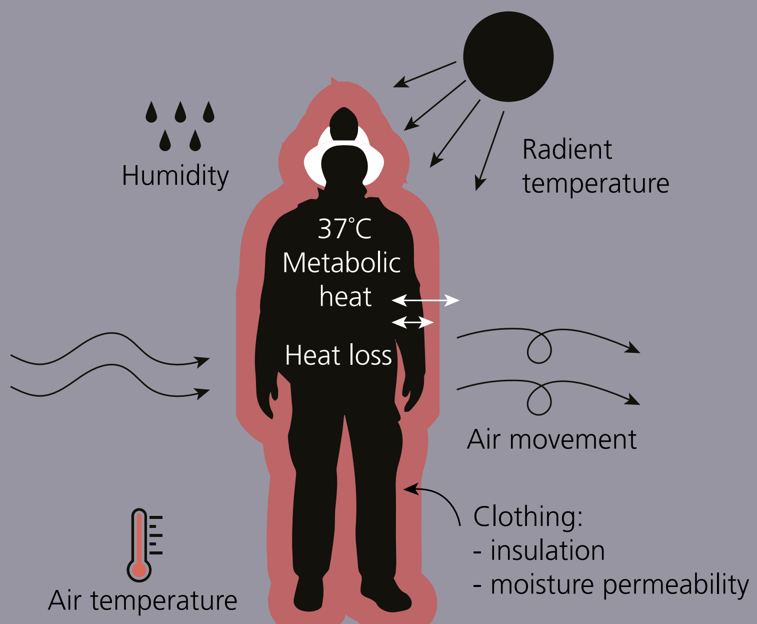


Figure 25. The human thermal environment.
Source: Parsons, (2002), editted

According to Parsons the human body has three ways of losing heat: radiation from the skin, evaporation from sweat and heat loss from respiration. The heat gain from metabolic heat is the total energy produced by burning food with oxygen reduced by the total work that is performed.

For firefighters, there are some circumstances which deteriorate the situation. He has to wear the protective equipment which limits the ability to lose heat and the metabolic heat is hight because of the exertion he has to make. Also the environmental temperature is hight due to fire or sunlight (in summer) and the work intensity can shift quickly making it difficult for the body to anticipate.

There are three states of heat stress (Turner, 1969), see figure 26 on the next page. In zone A, there is no heat stress. Zone B has an increased heat stress but the body is able to maintain a constant temperature however, sweating and the heart rate are increasing. In Zone C the core temperature rises and heat illnesses could occur.

There are four types of heat illnesses ranging from not dangerous to deadly fatality (Brandweer A-A, 2013): heat rash, heat cramps, heat exhaustion and heat stroke. Heat rash and heat cramps are mild forms. Heat rash is a reaction of the skin, and heat cramps expresses in muscle cramps. Heat exhaustion is more serious and without proper intervention it could become a heat stroke, the heaviest and deadliest form. Heat exhaustion symptoms are exhaustion, dizziness, headache and sometimes loss of consciousness. Heat stroke could mean mental confusion, convulsions and also loss of consciousness and is often fatal or causes permanent neurologic damage (Bouchama & Knochel 2002).

In diagnosing the different heat illnesses, it is important to keep an eye for symptoms, however as mentioned before, this is easily ignored during hectic situations and often comes too late. Heat rash is a reaction of the skin when the skin is dirty with lots of sweat, however there is no good indicator for. Heat cramps occur when there is a shortage of salt in the body. Measuring the composition of the sweat can be used as an indicator. Heat exhaustion and heat stroke are the most important factors to measure, therefore you need to keep track of the core temperature, heart rate and blood pressure.

Heat exhaustion (Howe & Boden 2007):

- High temperature: 37-40
- High heart rate: Tachycardia (+100)
- Low blood pressure: hypotension (systolic 90mmHg and diastolic 60 mmHg)

Heat stroke

- High temperature: 40+

These indicators are standards, however different people react differently in situations, depending on the physical condition according to Mol (2017). Therefore it is necessary to gauge the system for every person, which means needing personal information like age, gender, weight, height and physical condition (physical condition will be described later at the 'energy level' part) of a person in combination with soft variables like the rate of exertion, temperature sensation and humid sensation at a certain moment (Marriott, 1993).

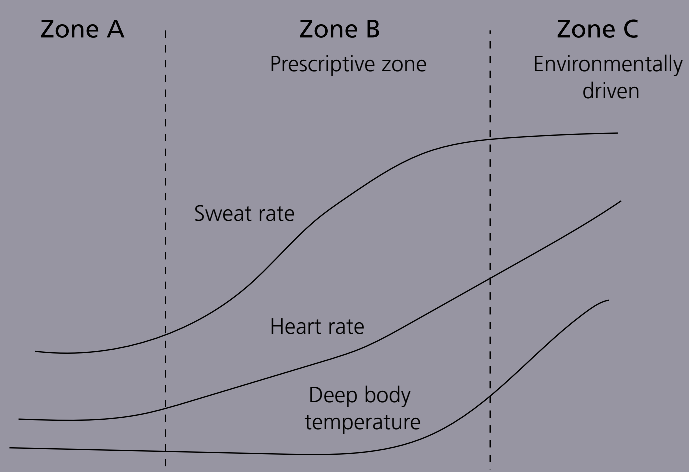


Figure 26. The stages of heat stress.
Source: Parsons, (2002)

Dehydration

Measuring dehydration is important to know if water intake is necessary.

Firefighters can become hydrated when the loss of water exceeds the water intake. A decrease of three to four percent of water in the body is tolerable by most people without any problems (Dill, & Costill, 1974). A five to eight percent loss could cause fatigue and dizziness, ten percent causes physical and psychological problems and fifteen to twenty-five is fatal (Ashcroft, 2000). For firefighters it is important to keep on drinking during their activities because it is necessary for cooling the body. When a firefighter loses a lot of sweat and doesn't take water, his blood will dry out making it harder to pump the blood through the blood vessels according to Ashcroft.

Dehydration can be diagnosed when the person feels thirsty, but that is already too late (Edwards, & Noakes, 2009). More precise monitoring methods include measuring the composition of urine or sweat, the interstitial fluid or blood glucose.

Oxygen

In situation where the air is polluted with smoke or toxic gasses, firefighters use a compressed air breathing apparatus. However, it is important to keep track of the amount of oxigen in the tank.

Suffocation caused by smoke is prevented by the breathing apparatus. But there is always a danger of having not enough oxygen in the tank to get into safety. Therefore the firefighters train to calculate the necessary oxygen during a deployment from the pressure gauge. It is important for the firefighters to calculate this by themselves and not use technology for it because it is influenced by a lot of factors which are difficult to be predicted by software.

Mental stress

When the mental stress rises during the deployment this could be an indicator for the commander that there is something wrong or that the firefighter sees something shocking.

Several aspects can change the level of stress of a firefighter. Like witnessing a shocking situation (e.g. a deceased or injured victims), or being afraid when he cannot find the way out. Because the commander is responsible for his crew, it is crucial for the commander to know when one of his crew members is in a stressful situation and is in need of help. But also mental stress can cause psychological problems like post-traumatic stress disorder (Haslam, & Mallon, 2010).

Measuring mental stress directly is not possible, but it is possible to assess the level of mental stress by interpreting the physiological response of a person (Kumar, et al. 2007). Heart Rate Variability (HRV) analysis is commonly used to make an assessment of mental stress and therefore it is necessary to measure heart rates over time. The problem with this method is that the heart rate variability is also influenced by the exertion of a person. This could be rectified by tracking the activity of a person. More research need to be done in order to be able to make a good prediction.

Energy level

This indicates if a firefighter is deployable for a certain activity

When the physical fitness of a firefighter is not good, there is a potential danger during a call out or in training. He could become exhausted and making mistakes or it could potentially contribute to other complications like heat stress (Parsons, 2002). The physical fitness can change from day to day and is depending on a lot of factors. For a firefighter, it is usefull to know his own condition at a certain moment, this could help him to assess the potential danger he is facing. This information could also be usefull for the commander, but due to the privacy sensitivity, it is important to check in what way this information can be shared.

The physical fitness of a person is strongly related to the maximal oxygen consumption (VO2 max.). There is a linear relationship between VO2 max. and the heart rate. Variables needed for calculating VO2 max. with the heart rate are personal information (e.g. gender, age, weight) and the activity at that moment. (Firstbeat Technologies Ltd, 2017)

Sleep is important to heal and gain energy. Therefore the quality of sleep is a good indicator as well.(Widmar, 2003)

Factors for diagnosing:

Heat stress
- Core temperature
- Sweat rate
- Heart rate
- Blood pressure
- Personal information
- Physical condition
- Soft variables

Dehydration
- Composition of sweat
- Composition of urine
- Blood glucose

Mental stress
- Heart rate variability
- Activity

Diagnosing energy level
- VO2 max: heart rate, personal information and activity
- Sleep

Decision

For this project heat stress is the most interesting variable. Dehydration could be prevented when drinking enough during the day and there are a few solution on the market for monitoring hydration (LVL, n.d.). Mental stress is still difficult to measure and needs more research. Oxygen is already monitored by the breathing apparatus. For Heat stress and heat illnesses there is not a solution yet and it is difficult to prevent it. Monitoring fatigue is necessary for assessing the heat stress as well, therefore this will be partly included.

The temperature

To make a device that can assess the heat stress the most important variable is the core body temperature. The core temperature is, the temperature of the inner core of the body, including the vital organs and the blood.

There are a number of ways and means to measure the core temperature. General methods include mercury-in-glass thermometers, thermistors and thermocouples, radio pills, heat-flow meters and infrared thermometers. The different regional temperatures are the oesophageal temperature, tympanic temperature, forehead temperature, oral temperature, oesophageal temperature, subclavian temperature, intra-abdominal temperature, rectal temperature, urine temperature (Parsons, 2002), see figure 27.

"The optimal measurement of the core temperature depends on the usability for interpreting physiological stress and the practicality in use."

The following information is gathered from the book Human Thermal Environments by Parson, unless indicated otherwise. (Parsons, 2002)

Oesophageal temperature

An oesophageal temperature measurement is the most accurate, it represents the core temperature the best (Robinson et al. 1998). The measurement includes a sensor to be inserted through the nose. However the results are influenced by drink, food and saliva.
The same applies for the oral temperate, which also requires a closed mouth during the measurement as breathing is influencing the measurement as well.

Tympanic temperature

The tympanic temperature can be measured as non-invasive using an infrared thermometer (IR). According to Daanen (2006) this is an underestimation of the core temperature. However, the underestimation stays the same when the temperature is increased or decreased, making it possible to calculate the real temperature when calibrated. Moreover, it is important that the IR light is directed at the tympanic and that it is not influenced by outside conditions.

Intra-abdominal temperature

The intra-abdominal temperature can be measured using a sensor in the form of a pill that needs to be swallowed. The pill sends out a radio signal that is related to the temperature. This is an accurate measurement and can be used over a long time while it continues recording the core temperature. However the use of the pill is not practical for everyday use since it needs to be swallowed and afterwards it needs to taken out of the faeces.

Forehead temperature

The forehead temperature can be easily affected by the surroundings when air is moving across the face. Therefore it is not a reliable measurement.

Subclavian temperature

The subclavian temperature can be measured via the armpit which gives a rough estimate of the core temperature and is only possible when the armpit is closed, making it impractical in usage for a firefighter.

Rectal temperature

The rectal temperature measurement is, besides it being unpleasant, only an average of the core temperature and reacts slowly after temperature change. Moreover, it is affected by the blood from the legs during exercises.

Urine temperature

A measurement of the urine temperature is a good representation of the core temperature when measured in the flow of urine. This method however is not practical for continuous measurement.

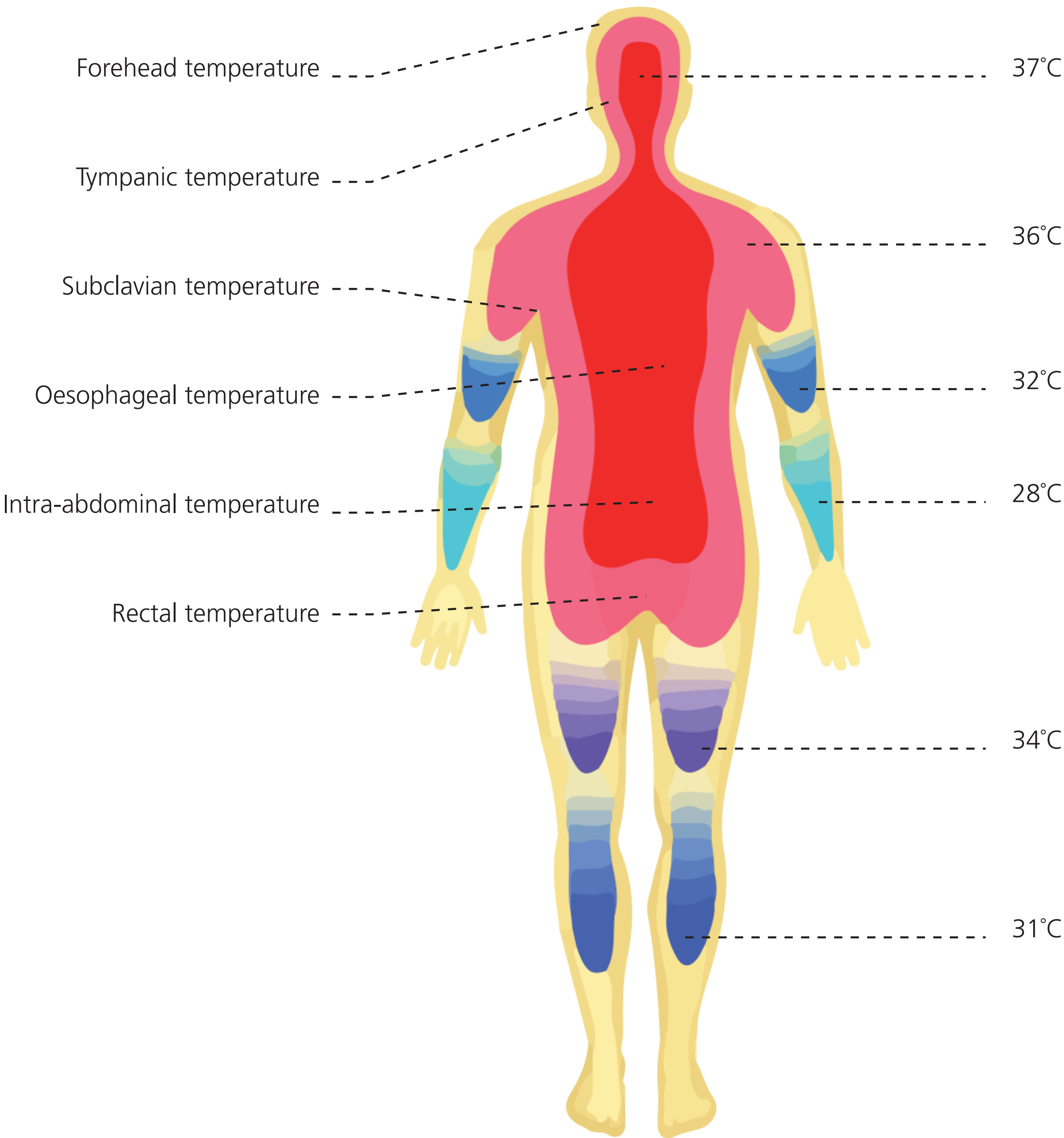


Figure 27. The temperature in the human body.
Source: Dräger, (2014) editted

<u>Decision</u>

A tympanic temperature measurement seems the most useful for firefighters. It is an accurate measurement and is the most practical in use. The ear is an interesting place for measurement since it can be combined with a communication device. Therefore the two design directions 'Monitoring health' and 'Smart Communication' could be combined into one product, a smart earpiece. It is also a place where a lot of biometric data can be measured. Beside temperature it is possible to measure the heart rate, blood pressure, stroke volume (Da He, 2013) and due to the presence of sweat it is possible to detect the composition of it.

A smart earpiece could have multiple values:

› By measuring biometric data it can provide warnings, collect data and help in training.
› It can also improve the communication by connecting it to the radio, filter out noise and enhance voices.

Storyboard

The storyboard in figure 28, investigates the possible scenario of a smart earpiece. This storyboard is not the real representation of the final concept, but it will be used as a basis to create the final concept in the next chapter.

Conclusion

Firefighters are facing great risks during their work. This implies injuries from external factors but also the physiological effects. It is not certain, but there are a lot of implications that cardiovascular deceases are the main cause of deaths among firefighters in the Netherlands. From the physiological responses to firefighting, the effects on the cardiovascular and thermoregulatory systems are the most severe.

For determining the deployability of a firefighter, the following factors are important to assess: heat stress, hydration, mental stress, energy level and oxygen. Heat stress is a cause of both cardiovascular and thermoregulatory problems. Therefore heat stress is chosen to be continued with in the rest of the project. Energy level will also be incorporated because it is influencing the heat stress.

Heat stress is the heat gained inside the body. This is the result of a reduction of heat loss due to the firefighter's suit or warm environment. Heat stress causes heat illnesses. The most severe and even fatal heat illness is a heat stroke which results from a heat exhaustion. It is possible to recognize the symptoms of heat exhaustion and heat stroke without the help of measurement equipment, but firefighters tend to ignore these due to the hectic of the situation and it could mean it is already too late.

The difficulty of measuring heat illnesses is the fact that everyone reacts differently on the physiological changes. This is depending on a person's physical condition. Therefore a smart system is needed that calibrates the calculation based on personal data, soft variable like the rate of exertion, temperature sensation and humid sensation and the maximal oxygen consumption (VO2 max).

For assessing heat stress, a measurement of the core temperature is needed. The most practical place to do a continuous measurement of the core temperature is the ear using an IR thermometer. An IR ear thermometer could be combined with a communication device, which could also improve the communication between firefighters.

Key results

- Cardiovascular disease is likely to be the number one cause of deaths among firefighters
- Heat stress has effect on the deployability and has long term effects on the health of a firefighter.
- The measurement of cardiovascular stress and hydration are important to incorporate in the future
- The characteristics of heat exhaustion are a temperature between 37°C and 40°C, a heart rate higher than 100 bpm and a blood pressure lower then 90/60 mmHg
- Measuring the core temperature in the ear is an underestimation, therefore a calibration is needed.
- To ensure an accurate measurement of the core temperature the temperature of the eardrum needs to be measured and it should not be influenced by external factors.

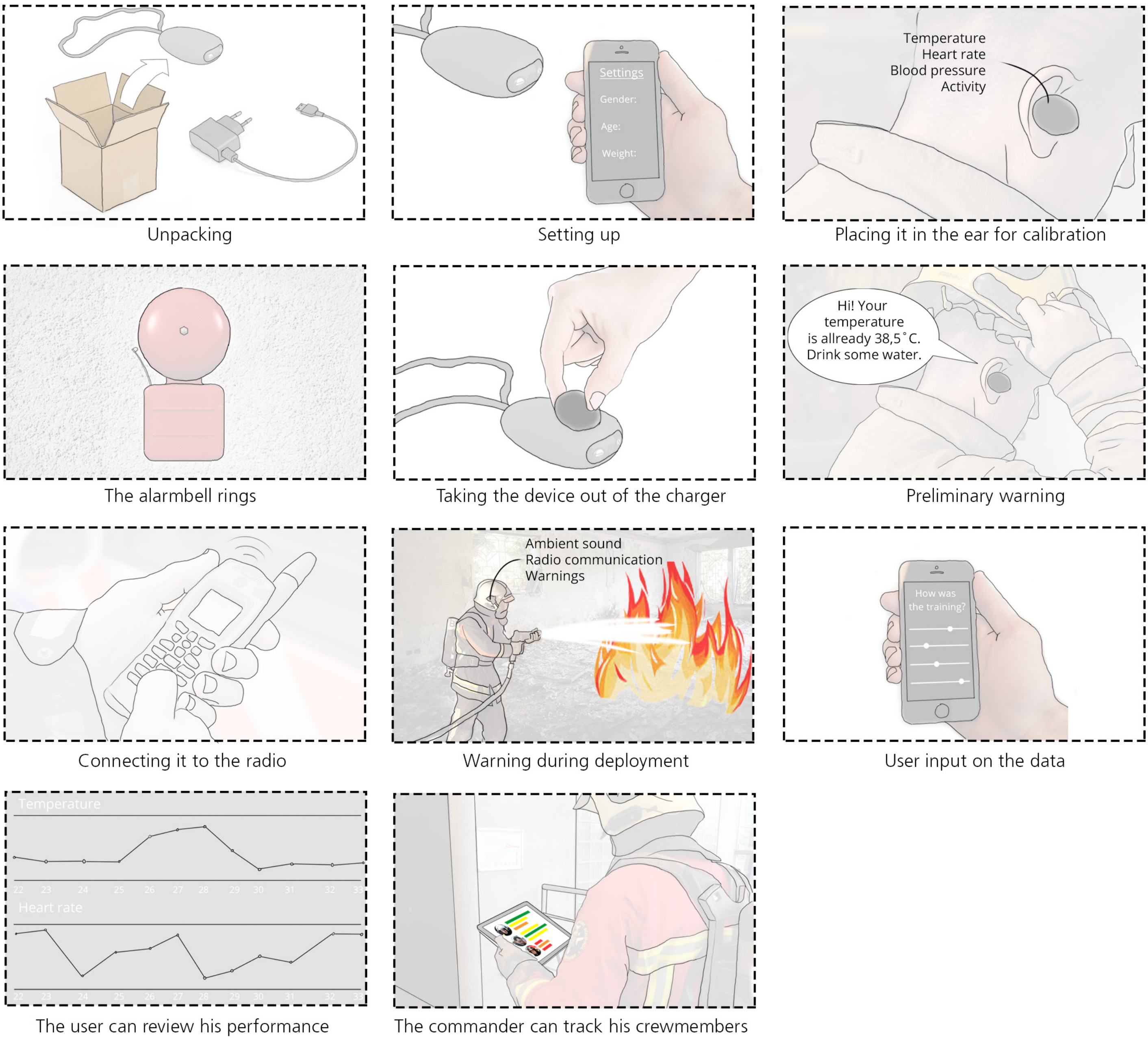


Figure 28. Storyboard of the smart earpiece

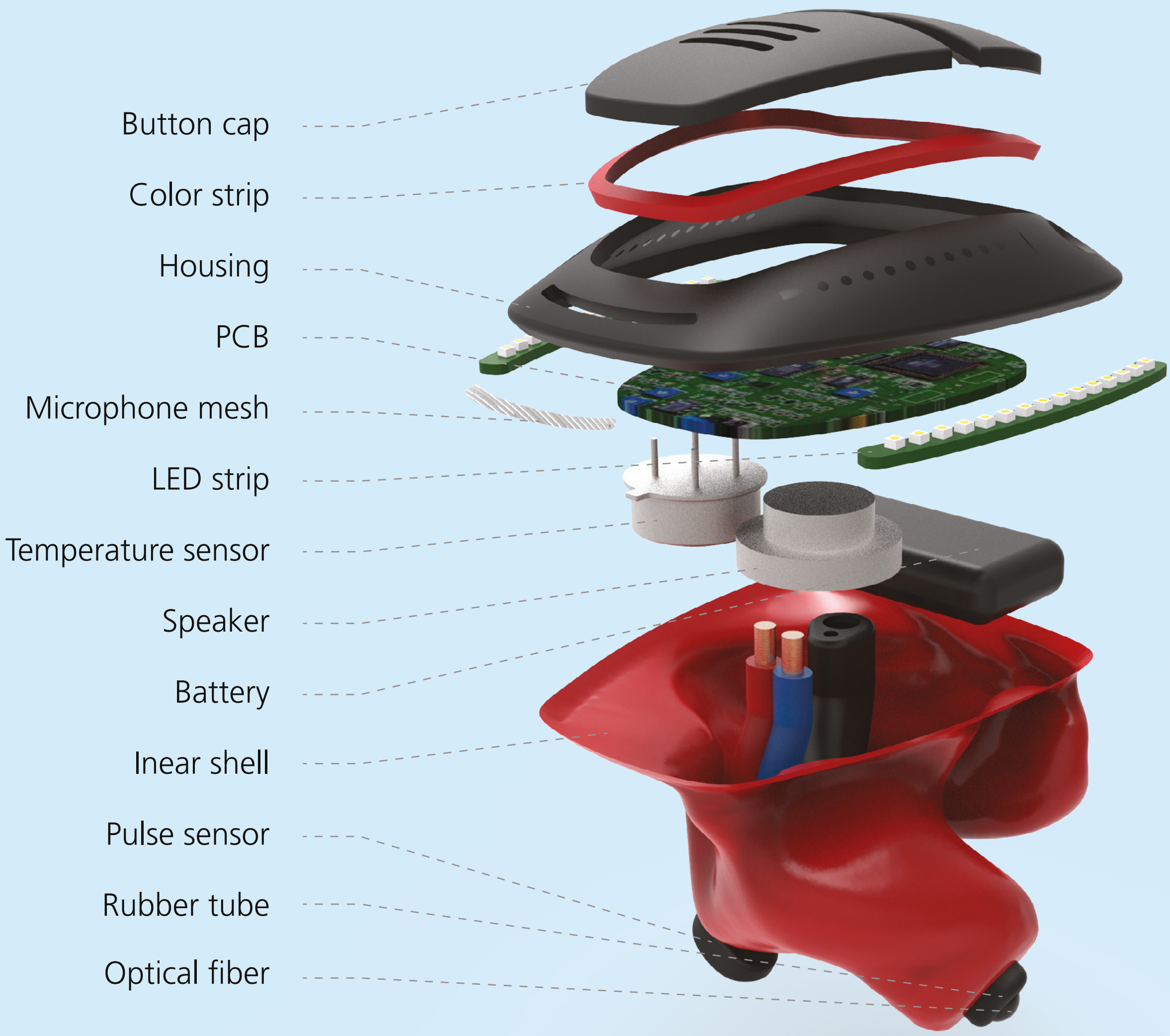


Figure 29. Exploded view of the QuantiFire earpiece

5. FINAL CONCEPT: QUANTIFIRE

This chapter describes the final concept as a result of the concept design process. The concept is detailed in a way that it can be tested with the user and in order to discuss the project with the board of the fire department for the further development.

Approach

To define the concept, a customer journey is created to plot out the touch points of the different stakeholder and a morphological chart is used to give a representation of the solutions for the functions and sub-functions of the concept in a systematic way. This leads to the decision of the final concept. The interaction of this concept is described in the form of a scenario.

The design of the product is a result of a form study, in which different designs and forms are tested by making drawings and models from clay and by using 3D printers.

The final design is further detailed by looking at the different components inside the device, the warning system, the charger case, the app and how it should be produced.

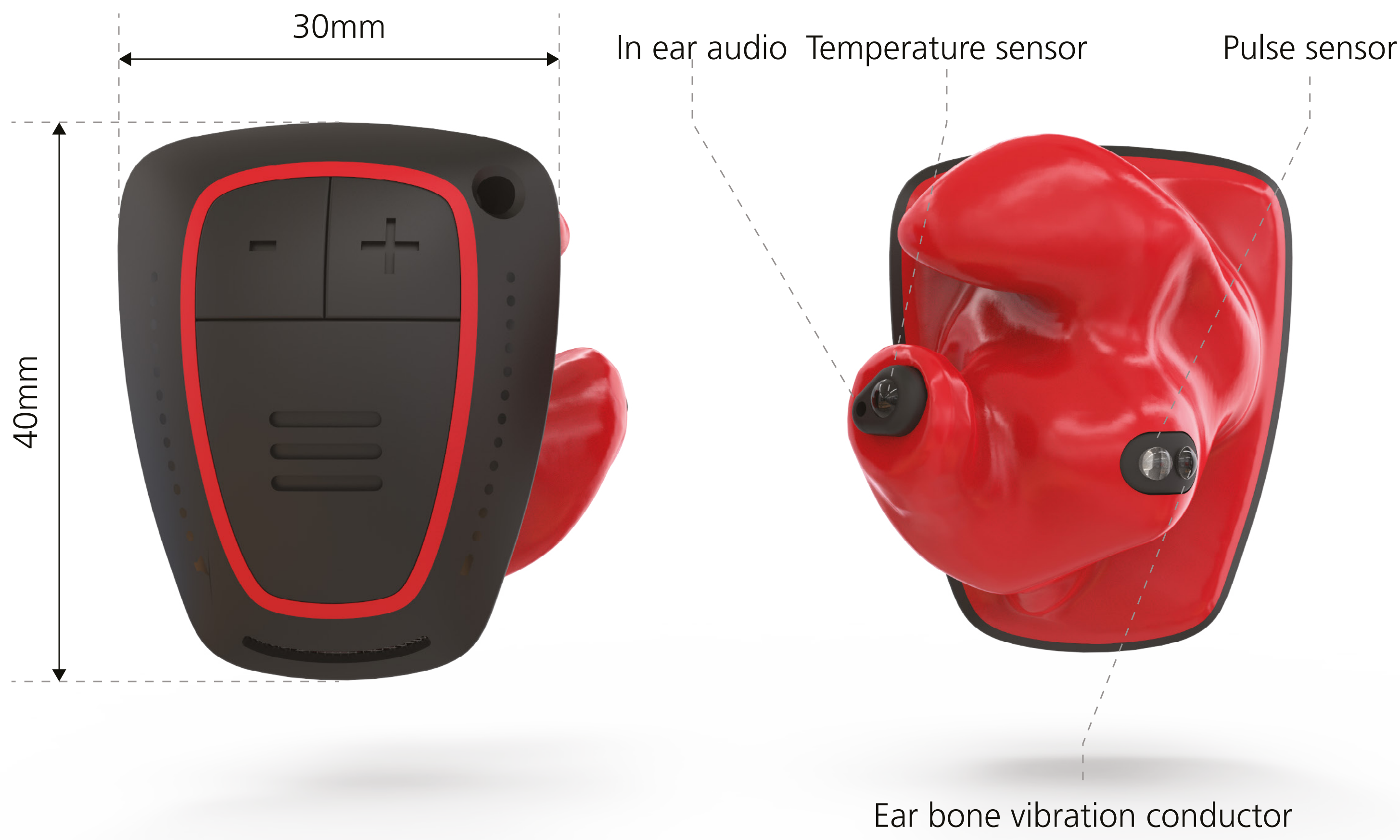


Figure 30. Front and backview of the QuantiFire earpiece

Defining the concept

Concept vision

As mentioned in chapter two, the fire department could benefit from collecting data. It enables organizing the fire department in the most safe and efficient way. To start collecting data, collecting health data is chosen as a first step. This is easy to collect and could have short term value, which is the prevention of physiological injuries.

The smart earpiece developed in this project focuses on the prevention of heat related illnesses. It is part of a product-service system, the QuantiFire system, which also includes a smartphone app, a central server and additional it could be connected to other systems like the MOI system (mentioned in chapter one) for enabling the commander to track his crew members or to other biometric data measuring devices. By generating data, this system predicts the physiological risk potential of the user and warns the user in order to prevent injuries. Next to that, the data is used by the firefighters to learn from their performances during call-outs or training and could it be used for research.

Customer Journey

The customer journey, figure 31, defines the different stakeholders that interact with the QuantiFire system. It investigates their needs and activities at the different moments and how the system responds to that on one of its channels.

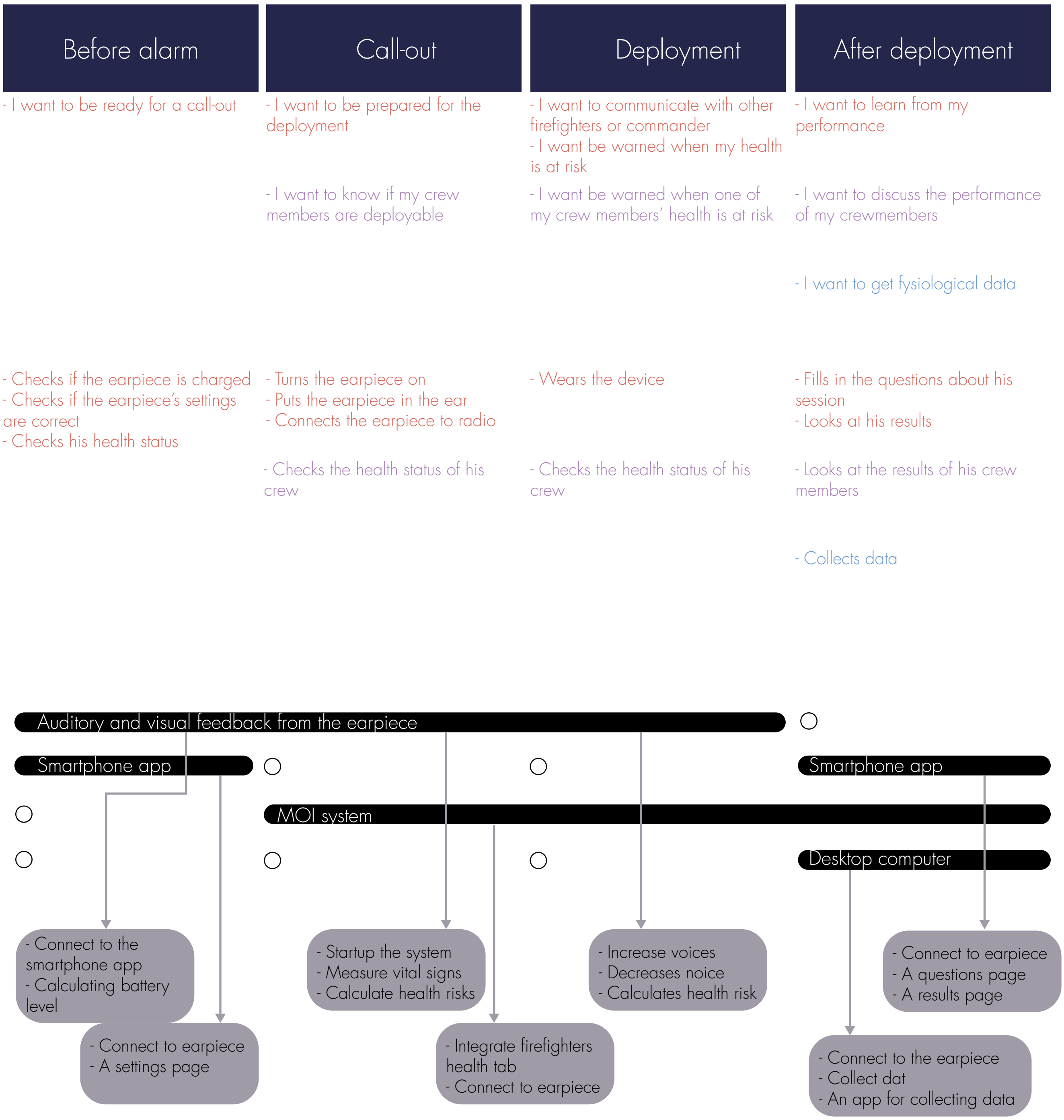


Figure 31. The customer journey of the QuantiFire system

Morphological chart

In the morphological chart (figure 32) the different solutions for the different functions of the smart earpieces are explored. The functions included in the morphological chart are based on an extensive process analysis resulting in a process tree (appendix 6).

<u>Body variables</u>

Following the health analysis, we can conclude that in order to fully assess the health risks of a firefighter, the following body variables are necessary:

› Core temperature
› Heart rate
› Blood pressure
› Sweat rate
› Energy level

Core temperature:
Measuring the core temperature via the ear should be measured using contact less temperature measurement. Contact with the eardrum causes significant pain and harbors the potential risk of tympanic perforation (Parsons, 2002). Therefore infrared temperature sensors are mostly used for measuring the tympanic temperature.

For selecting the right temperature sensor the following factors are important: the temperature range, distance to the object that needs to be measured and the dimensions of the sensor. Because the body temperature is being measured, a temperature range between 20˚C and 50˚C is enough. The distance between the sensor and the eardrum is dependent on how far the sensor can be inserted into the ear canal.

Heart rate:
For monitoring the heart rate there are three methods: optical based, sensor based and auscultation based (Kevat et al., 2017).

According to Kevat, in medical applications, mostly sensor based technologies are used due to the accuracy of the measurement. However, because it requires good placement of the electrodes it is less practical for daily use. The types of sensor based technologies are electrocardiography (ECG) which uses electrodes and is the most commonly used, plethysmography which uses capacitive sensors and piezoelectric detection which uses piezoelectric sensors. More technologies exist, but they are still in early development.

Optical based technologies are the most usefull for a wearable device and are also widely used in wearables and other home applications (Van Hooren, 2016). This technology, called photoplethysmography (PPG), is based on an optical sensor that detects changes in the color of light in a body part due to absorbance of wavelengths by the arterial blood. There are two kinds of PPGs, transmission and reflection (see figure 33). Transmission requires a small tissue, restricting it to certain locations on the body while reflection can be used on almost every location.

Blood pressure:
Blood pressure is more difficult to measure than heart rate. The mostly used methods in clinical applications are invasive technologies that measure blood pressure by using an arterial catheter, and non-invasive technologies as auscultation and oscillometric based on cuff occlusion (Da He, 2013). All of these technologies are not applicable for a

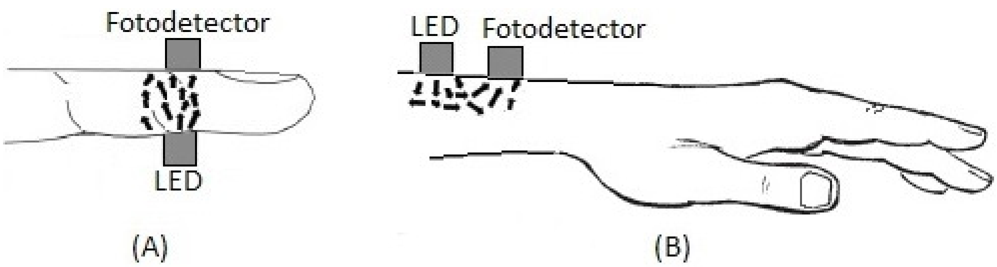


Figure 33. The two methods of PPG measurement, left: reflection, right: transmission
Source: Van Hooren (2016)

Figure 32. Morphological chart with the solutions for the different functions of the smart earpiece

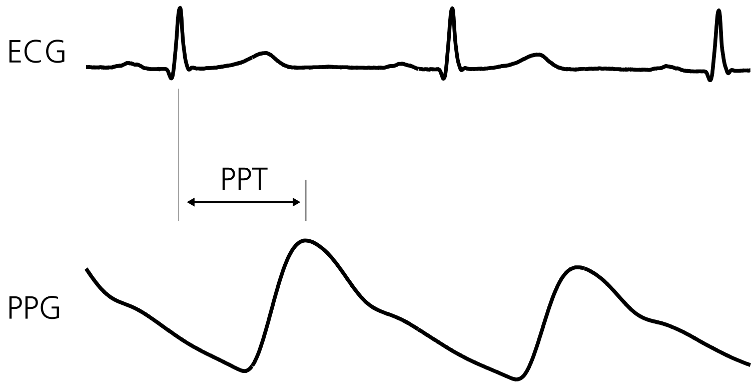


Figure 34. Pulse transit time from a ECG and PPG diagram
Source: Allen (2007) editted

wearable device that needs to measure the blood rate over time without any discomfort for the user. Another way to obtain the blood pressure is by calculating it from two different measurements: PPG and a simplified ECG measurement. With these two measurements, the pulse transit time (PPT) can be measured (Allen, 2007), see figure 34. PPT is correlated with the blood pressure (Fung et al., 2014). PPG (used for measuring the heart rate as well) and ECG can both be implemented in wearable devices. However, for a usable ECG measurement, the electrodes needs to be placed at two different locations. This makes it difficult to implement into one earpiece and therefore it is not included in the final concept. In chapter 6 the possible locations of the sensors will be investigated for future development.

Sweat rate:
Wearable technologies that can measure sweat rates and detect the composition of the sweat are emerging. Capacitive sensors can be used to sense the humidity of the skin, this can be translated into the sweat rate. (Kraning, & Sturgeon, 1983) Because this technology is in an early state of development, it will not be included in the final concept.

Energy level:
To make an assessment of the firefighters physical energy level, it is possible to measure a few things as mentioned in chapter four: VO2 max (heart rate, activity and personal information) and sleep.

Heart rate will be measured using PPG. To measure activity, gps and an accelerometer are used. Personal information needs to be provided by the user, therefore this is investigated in the interaction part.

Sleep can be tracked using a smartphone app. This will not be included in this project as it focusses mainly on the earpiece, however, it is an interesting recommendation for future development.

<u>Stay in the ear</u>
Firefighters have to be at location within three minutes after the alarm sounds, therefore the time they have to prepare themselves must be as short as possible. Putting in the smart earpiece should therefore require as little time as possible. In addition, the sensors need to be placed exactly in the right position every time and preferably the temperature sensor is insulated from outside conditions, as mentioned in chapter four. Therefore the best option is a personal fitted earpiece which is custom moulded to everyone's ear, creating a perfect fit. The molding process will increase the cost price, but in this case it is more important that the device works in the most optimal way.

<u>Taking along</u>
The system benefits when the device is worn as much as possible, this enables it to learn from the user and therefore make a better estimation. To stimulate the user to use the device as much as possible, it is important for him to take it along easily. Wearing the device all day is, as indicated by firefighters themselves, is not an option. Their work shift is 24 hours and wearing something in the ear will eventually cause discomfort because of sweat, pressure, etc. A storage case with power supply is a good option. This charger, could be integrated into the firetruck. This ensures the device is always charged and at the location where needed.

<u>Turning on/off</u>
The user should always be able to force the device to restart, therefore a pushbutton is required as this provide tactile feedback and is more error prove than for example a touch button, a motion or a proximity sensors. However, it should be taken into account that the button is usable when wearing gloves.

<u>Advice/warn the user</u>
Because the smart earpiece is providing sound, the most logical way to warn the user or providing advice is by voice. A vibration in the ear is

considered disturbing, since this produces sound. Using a display would be an option when it is easy to use without extra steps. An augmented reality (AR) display in the mask could be an option. However, because this technology is considered to be in an early state (Economist, 2017), this could be a recommendation for the future and not the focus of this project.

Interaction

Interacting with the smart earpiece while the user is wearing it, is necessary when the user wants to obtain information about the current status or when the device needs input from the user to learn through it.

For obtaining the current status, the same requirements applies as for turning the device on/off. This could be solved with a push button.

For providing user input, the most useful is a smartphone app. Firefighters have their smartphone with them the whole day and it is connected to the internet. Sleep tracking could eventually also be implemented in this app. Voice input, through speech recognition would be a possibility. However, this needs more developing to work flawless for firefighters.

Record sound

To provide sound from the surroundings, this sound needs to be recorded by the device. Next to that, the device needs to record speech sound as an input for the radio. Bone conduction technology is interesting for firefighters because it can record the direct voice of the person and is not influenced by noise from the surroundings (Neovictory, 2011). The army uses throat microphone because this enables communication in extreme noisy or windy environments and it can even pickup whispers which could be necessary when silence is required ("About Throat Mics", 2017). For firefighters this could be a solution for the communication problems they are facing. However, it is not considered practical for firefighters to put something around the throat, since it will interfere with the jacket. Therefore an ear bone microphone is the best solution.

Providing Audio

The device needs to provide audio from the radio and from the surroundings due to the fact that the ear canal is blocked. The option of leaving an open canal is not a possibility since the sensor needs to be insulated from outside conditions, as mentioned in chapter four. Therefore an earphone speaker is the best option for providing audio from both the radio and the surroundings.

Charge

Because the earpiece is a custom moulded part and it needs to be water resistant. Wireless charging is the best option. This enables a standardized (same for all users) charging case. To ensure the earpiece will not turn off during a deployment due to battery shortage, a wireless charging module could be implemented into the helmet.

Computing

The computing power will be divided over the separate devices in the system. However, it is necessary for the earpiece to operate without any connected device.

Connection

The connection between earpiece and smartphone will happen over Bluetooth 4.0, since this provides low power consumption (Dunn, 2010). The connection between earpiece and the radio could be setup using an audio jack cable or by using Bluetooth, if this is enabled by the radio. For further developments, the earpiece could communicate with the C2000 network immediately. This would make the radio unnecessary.

Interaction

The interaction with the system will be explained by means of a scenario. This scenario represents the final product when the system is fully developed. Before this scenario is possible, more research on the data needs to be done, this will be explained in the next steps in chapter seven.

1. In order to make the custom fitted earpiece, the firefighter needs to go to the hearing care professional to make a 3D scan of the inside of the ear. Therefore a self-hardening material will be injected into the ear to make a mold. This mold is used to make a 3D model using a 3D scanner. The final product is then generated in the computer and printed using a 3D printer. The sensors and other electronics are placed inside the 3D print by hand.

2. When the earpiece is used for the first time, the system needs to be configured using the QuantiFire app. The configuration process contains; connecting the device to the smartphone using Bluetooth, filling in a personal profile of the user and the calibration of the sensors.

3. The device will be put in the charging case that can be installed inside the firetruck.

4. While preparing for a fire training or for a call out, the earpiece is taken out of the charger case. This will automatically turn on the device. The power button can be used to turn the device on or off by hand. This only works when the device is not inserted in the ear. The same applies to the volume buttons.

5. The device is then inserted into the ear and connected to the radio using a cable or wireless connection, if this is supported by the radio. Using the sensors, the device automatically detects when it is placed in the ear. If this is the case the device starts generating physiological data. This data is used to analyze the current state of the firefighter which is fed back to the user only one time, just after the device is inserted. This feedback is provided using a computer voice.
   The function of the push buttons changes when the device is placed in the ear, it is not possible to change the volume or turn the device on or off. However, when the home button is pressed, the device gives an overview of the current state of the body and provides advice to its user.
   Because the earpiece blocks the ear canal, which is necessary for reliable temperature measurement, the hearing capability is reduced. Therefore the device records the ambient sound using a microphone and plays this sound over the earphone speakers. This is a digital sounds which makes it possible to analyze the sound of voices and of background noise. Through software, the volume of the voices will be increased, while background noise is being reduced.
   When a voice is recognized by the system, all auditory warnings from the system will be put on pause, enabling the user to focus on the conversation and to remain on line.

6. During the fire training or call out, the earpiece is used for two way communication via the radio. For speech, the device contains an ear bone microphone. This bypasses the conduction of audio through the air from the mouth to the device, instead, the sound of the voice is immediately received through the bones. This drastically reduces noises caused by the surroundings, since it only records the voice.
   In case the user takes out the earpiece while it is connected to the radio, the device will shut off and the speaker of the radio will take over.

7. When the firefighter's physical condition is critical, the device will automatically warn the user and provide advice about the steps that needs to be taken.

8. After the exercise or call out, when the device is taken out of the ear, the user will receive a notification from the QuantiFire app, indicating

that the user needs to fill in some questions about the previous session. This data will be used to calibrate the system to make the predictions more accurate.

9. The QantiFire app can be used to view the performance of the user at a certain moment. This data can be used for training. It enables the user to learn to know his own body and to understand its limits. The app also provides the possibility to changes his profile, share his data with other users, change the setting of the system (e.g. the volume level, the type of assistance and the moment of the warning) and to add other devices to the system such as an extra earpiece or the QuantiFire shirt that enables the measurement of the blood pressure, this will be explained in the recommendations in chapter six.

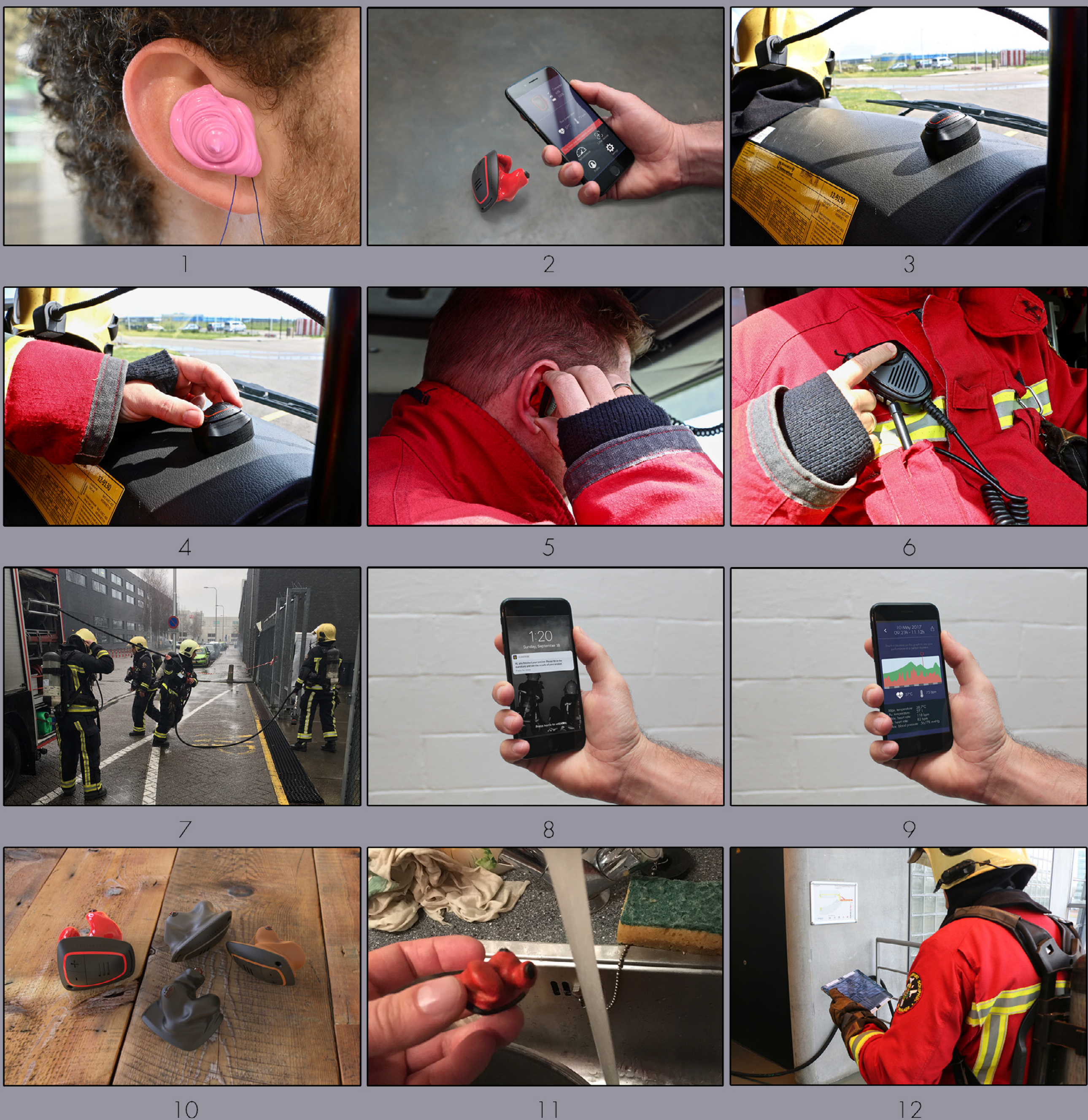


Figure 35. Interaction scenario of the QuantiFire system

10. When the device is not in use, it is preferably placed inside the charger case. This keeps up the battery level and prevent losing the device. However, there will always be a situation in which the device is not placed in the charger. Therefore it is important to easily recognize your own device. The colored strip at the front of the case and the custom made earpart are therefore available in different colors. The user can choose his or her preferred color. To exactly distinct the different devices to different people, the custom made ear part contains engraved initials of the user.

11. To stimulate the user to wear the device as much as possible, which will improve the data analytics, the earpiece can be used to listen to music or make personal phone calls as well.

12. Because the device is water resistant, it can be rinsed under the water tap. When parts are broken, the device needs to be returned to the supplier.

13. The insights in the current physiological state of the user can be useful for the commander as well. Therefore the device can be connected to the MOI system (Mobile Operational Information system) on the tablet that is used by the commander during a call out. This enables the commander to keep track of the physical condition of his crew members. It could also be considered to give the pump driver access to this data. He is the one that stays near the firetruck and has time to keep track of this data.

Figure 36. Mood board

Figure 37. Modern design study

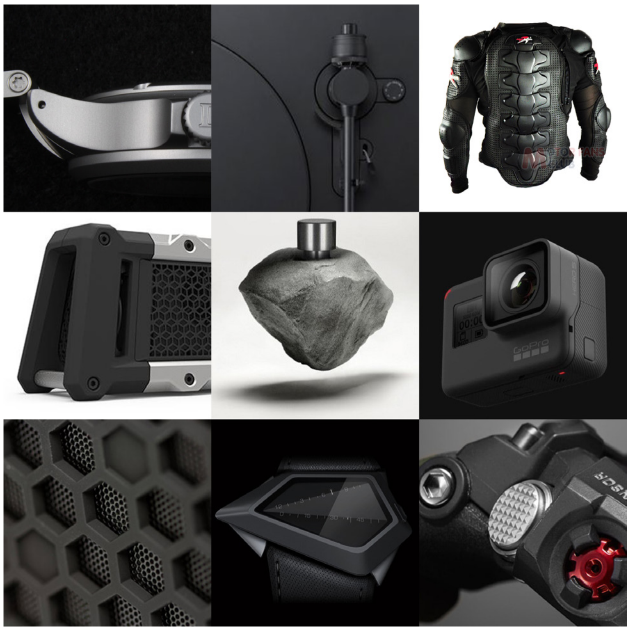


Figure 38. Robust and tough design study

Final design

The styling of the components of the system, should fit with the style of the firefighting context. This means it needs to have a modern, though and robust appearance. To define this appearance, a mood board is created with current firefighting products that provides inspiration for the form, color, material and detailing, see figure 36. The products in the mood board are used by firefighters and therefore accepted for its style. Modern product aesthetics are often reflected in smart and minimalistic design with contrasting materials and colors, see figure 37. Robust and tough designs often incorporate dark and high contrasts colors, straight and sharp lines and raw materials and finishes, see figure 38. To achieve a design language that fits within this context, an iterative form study (including sketching, 3D modelling, claying and rapid prototyping) was performed which led to the final styling of the earpiece and the smartphone app, see figure 40 & 41 on the next page

Smart earpiece

The earpiece is a combination of an organic custom made part for inside the ear and a part that stays outside the ear (the housing). The contrast between the two parts reflect softness and comfortability for the user but at the same time the protectiveness from the outside. The shape of the housing is based on the shape of a turtle shield, which act as protection for the vulnerable turtle inside. A modern, though and robust appearance is achieved through its simple curved shape, the dark contrasting colors, material finish and detailing.

The shape of the case and the positioning of the buttons indicates how the device should be placed, enabling the user to easily and quickly put the device in the ear. The main button, the power button, is easily accessible by its large and protruding shape, while the volume buttons are smaller and hidden at the top.

Strips of light at both sides of the device indicate if the device is on or off and the status of the battery and of the volume level, see figure 39. If the device is in pairing mode (pushing the power button for five seconds), the lights turn blue.

The back of the case flows over into the custom made part, this makes the whole earpiece as one piece. The custom made earpiece holds all the sensors, ensuring they are located in the right position. This piece fits comfortable and stays stable in the ear.

App

The styling of the smartphone app, is built upon the corporate identity of the Dutch fire brigade, which is reflected in the colors and fonts and the QuantiFire logo. This makes it easier for firefighter to relate themselves to the system. To be distinctive not the color red, which is the main color of the fire department, but a blue color is chosen as the main colour for the app.

Figure 39. Led strips

Figure 40. QuantiFire smartphone app (load screen & home screen)

Figure 41. The QuantiFire earpiece. Left: the sensors. Right: the two part

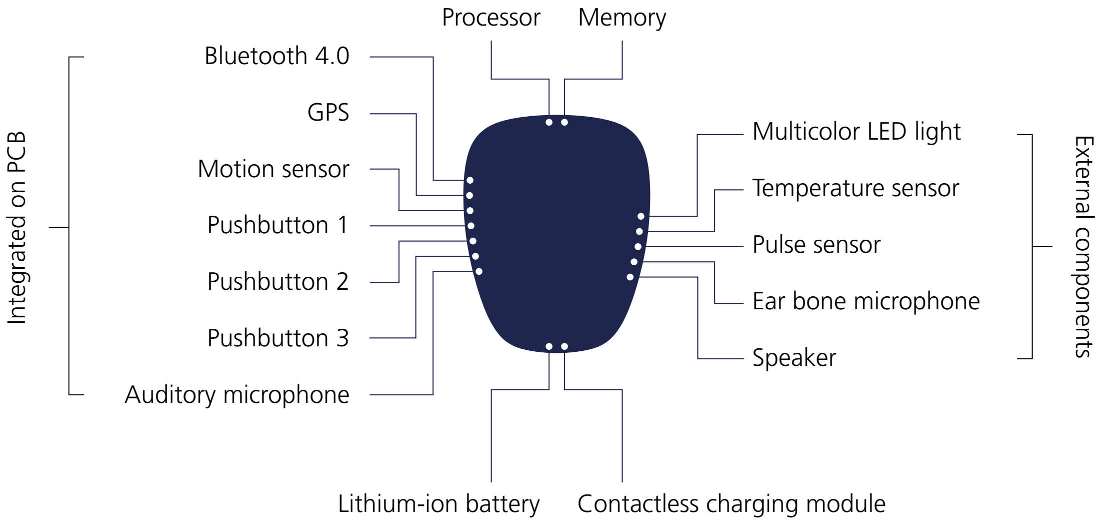


Figure 42. Simplefied electronic circuit.

Detailed design

Components

The temperature sensor, pulse sensor, ear bone microphone and speaker all need to be placed inside the ear. This is a small area for these components, therefore the temperature sensor and the speaker are placed near the outside of the ear and the sound and the IR beam are guided into the ear canal through a rubber tube and an optical fiber, see figure 41. The pulse sensor and the ear bone microphone are combined in one part that is placed in the opening of the ear.

The shield housing contains the main PCB with a Bluetooth 4.0 chip, gps and motion sensors to keep track of the activity of the user and three pushbuttons. An auditory microphone is connected to record the sound from the surroundings. Two LED strips provide feedback of the current state of the device to the user.

The processor is provided with a memory chip to make storage of the gathered data possible. In case of a Bluetooth connection with an internet enabled device, this data will be send to the main server.

Charger case

After each session, the device needs to be recharged to make sure, the battery will not run out during the next session. Therefore the earpiece can be loaded in a charging case which is installed in the firetruck, see figure 43. The earpiece is placed with the part that goes into the ear. This helps to keep this part clean in order to prevent the wearer to get infections in the ear. The earpiece is charged with a wireless module.

Figure 43. Charger case installed in the fire truck.

Warning

During a call out, a firefighter needs to focus on his job: saving people or extinguishing fire. All other things that needs his attention are an obstruction. Therefore it is not useful to burden the user with the statistics about his current body state. The device should inform the user only in the most undisturbed way and only at the right moments. To achieve this, the device only provides an overview of the body status at the moment the user puts in the device or when he pushes the power button while the device is in the ear. In addition, the device provides a warning signal at a critical moment.

Also, the way the feedback is provided by a computer voice is as concise as possible. The statistics are not explained completely, but the device makes an estimation of the risks and provide this together with an advice. For example, when the alarm goes off while a firefighter is working out in the gym. His core temperature could be increased already. The device can detect this and warn the user to first calm down a bit and drink some water.
This only applies for the computer voice feedback, when the device is connected to a smartphone, the user can see all his data.

App

Calibration:
The first time the QuantiFire app is launched after installing, the user has to walk through the setup steps, see figure 44. The first step is to connect the earpiece to the smartphone. Therefore the user needs to press the power button on the earpiece to activate the pairing mode, the lights on the device will turn blue. After the device is connected the user has to fill in his profile. His profile contains personal information like gender, age, height and weight. This information will be used to calibrate the analysis in order to make more accurate predictions. The user can also fill in his name and add a photo. This will be shown to other users of the app when they want to share their data. The last step of the setup is the calibration. For the calibration, the user needs to take a temperature sensing pill and put the device in the ear. The sensors from the earpiece will then try to get reliable data. This data is compared with the data from the temperature sensing pill. During the calibration, the user can continue with his normal work.

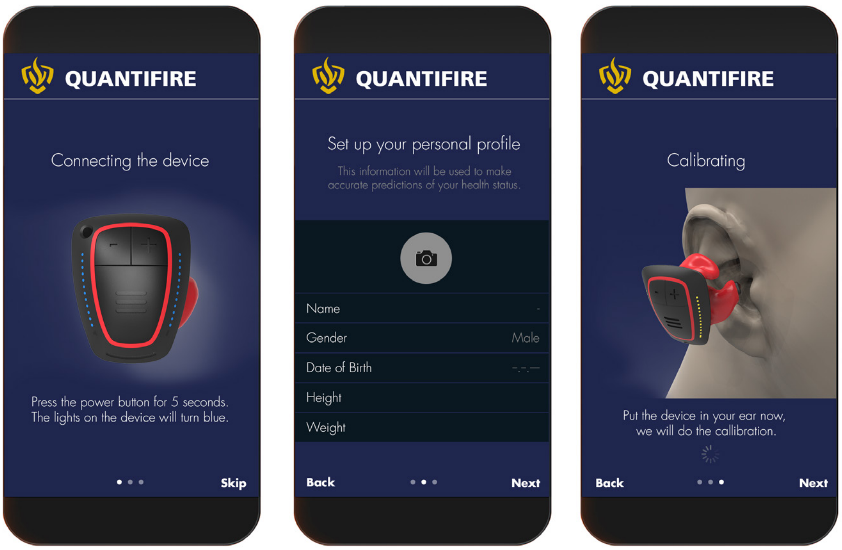


Figure 44. Callibration settings of the QuantiFire app. Left: connecting. Middle: Personal profile. Right: Callibration.

Home screen:
When the calibration is finished, the smartphone app can be used as normal. The app always starts with a home screen, see figure 45. This screen contains statistics of the device(e.g. battery and volume level), the current heart rate and core temperature from the user when he is wearing the device. Also four buttons to go to the performance and profile section, to connect other devices and to go to the settings. When another device is connected, for example the QueantiFire vest for measuring the blood pressure, more vital signs are shown on the home screen such as the blood pressure, sweat rate, etc.

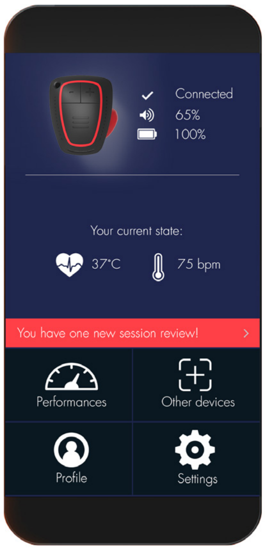


Figure 45. Homescreen of the QuantiFire app

Performance:
In the performance page, see figure 46 , the user can review all his previous sessions. A session is defined by putting in the device and taking it out of the ear. Per session, the user can see his maximum performance, but also the performance at a certain moment in time. It is possible to share a session with other users from the session page.

After each session, the app will send a notification to the user to ask him to fill in a few questions about that session. To go to these questions, a red bar is placed on the home screen, that leads to the questions page. The questions include what kind of session it was and how he felt during this session.

Profile:
The profile section can be used to update the users profile. Every month, the user is asked to update his profile to the current conditions. The weight for example could differ in that period.
In the profile section the user can connect to other users. Users who are connected in the app, can easily share data between each other. This stimulates people to frequently reflect on their data and to start discussion within the group, which helps them to learn from each other.

Other devices:
Other device, such as the QuantiFire vest, can be connected to the system to add the measurement of additional biometric data. The more biometric data is measured, the better the system can analyze the current physical health of the user.

Settings:
In the setting tab, the user can change the settings of the device as well as the settings of the app. Settings for the device include changing the volume, the computer voice and the moment and frequency of the warnings. The settings for the app include the current connected devices, change the moment of the notifications etc.

Figure 46. Performance review in the QuantiFire app. From left to right: notification, questions page, sessions page, performance page.

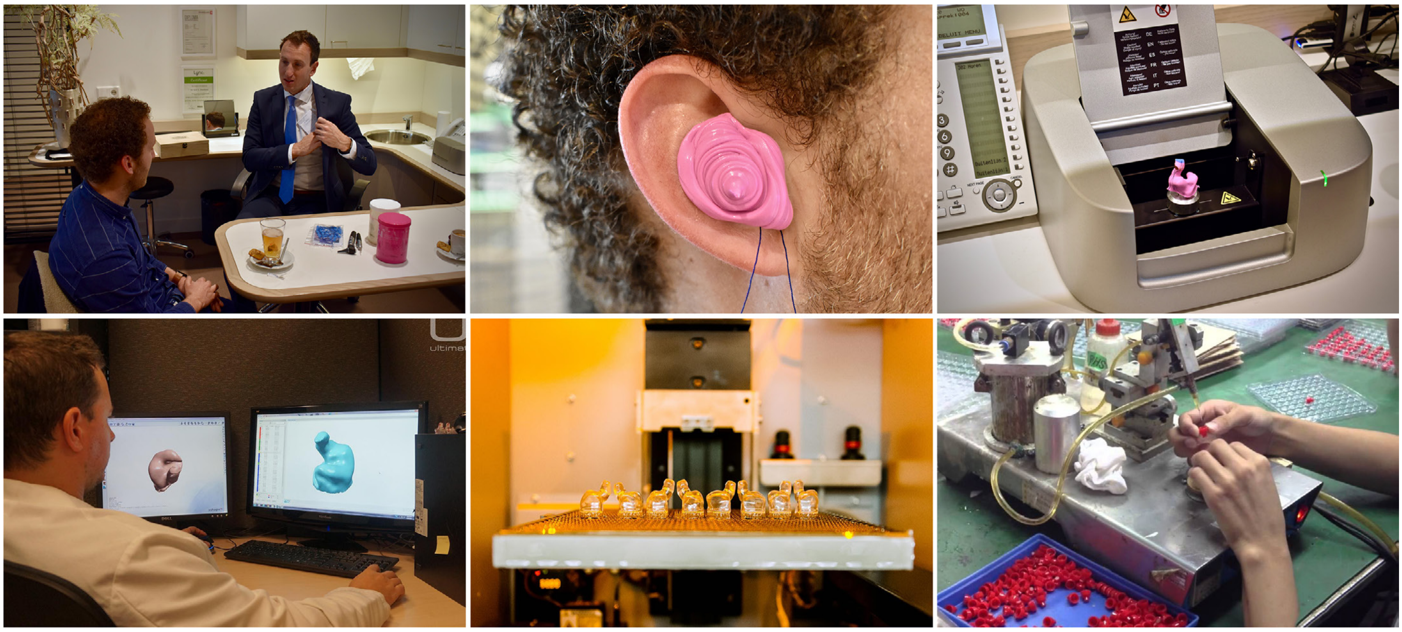


Figure 47. The stepst of the production of the earpiece

Production

For the production of the earpiece a distinction is made between the custom made in ear part and the shield that stays outside the ear. The shield is made in larger quantities and contains manufactured or standardised parts. The in ear part consists of a custom made shell and the components of the sensors. The shell is made from the 3D scan of the ear and is printed using a 3D printer. The components of the sensors are placed by hand.

Costs

The production costs are split into the costs for the earpiece and the application and software.

For a full calculation of the production costs of the earpiece, a more developed concept is needed, therefore a raw estimation is made. This helps to get an idea about the investment necessary for developing the final product.
For the estimation of the production costs, a quick decision is made about the materials of which the part will be made of. Cambridge Engineering Selector (CES) software is used to determine the materials. The full calculation can be found in appendix 5.

Total production costs for the earpiece:
A raw estimation of all the parts will end up at around €60 per earpiece. Because Schiphol is not going to produce the earpiece themselves, a supplier is needed, who will charge extra costs on top of this price to make a profit. This can make the total costs of the device around €150 to €200 per piece.

Components	Amount	Costs in €
Housing case	1x	0,0025
Rubber buttons	1x	0,0031
Battery	1x	0,75
PCB	1x	7,5
LED	2x	1
Sensors	5x	0,5
In ear shell	1x	30
Assembly	-	22
Total	12	62

Figure 48. Raw estimation of the production cost

Producing a simple app with user profiles and connected to a server will cost around €22.000. The whole system behind the app needs more development and will cost more.

Prototyping

During the design phase, a lot of mockups are made to try out different designs and to find the right proportion. These mockups are made from clay or are printed out in a 3D printer, see figure 50.

The final model, which is printed in color (figure 49), is used for the user test. In addition to this model, a working prototype is produced which acts as a proof of concept. This working prototype is made using an Arduino micro controller, a pulse sensor, temperature sensor, an ECG sensor and

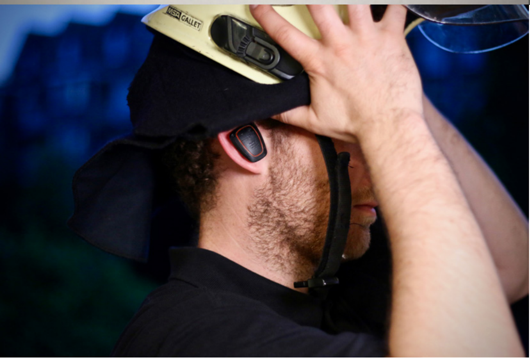


Figure 49. Mockup of the final design

an earphone with a microphone, see figure 50. This working prototype shows the possibilities of the sensors and it can be used to make the first measurements.

For the QuantiFire app a prototype is made using the Marvel app (Marvel App Prototyping Ltd, n.d.). This app works on the paper prototype methodology. This method, for creating software, helps to create user interfaces that meet the user's needs. It involves the use of images of the different screens of the interface. These images can be used in tests where the participants get to see a different picture if they touch a certain place of the picture. This simulates the application works. The Marvel app, is an app in which interactive interfaces can be made using images as well. The prototype of the QuantiFire app can be found here:

https://marvelapp.com/38bgf57

The prototypes are used in the final user test, which is described in the next chapter.

Conclusion

The final concept is a product-service system that helps firefighters in preventing injuries from heat stress. The system includes a smart earpiece, a smartphone app and additional devices could be added to the system to improve it or enable the exchange of collected data.

The smart earpiece is custom made for the user to ensure the perfect fit. Besides measuring biometric data, it improves the communication between firefighters by smart use of sound and an ear bone microphone. It can be stored in a case with a wireless power supply. Auditory feedback provides the user with warnings and advise about his health. Pushbuttons at the front of the device enable the user to turn the device on or off and change the volume. The battery and volume levels are indicated through clear led indicators. For more advanced interaction, an smartphone app can be connected to the earpiece though a Bluetooth connection. The app can be used to track the performance of the user and change the settings. Furthermore, it has a transparent audio system, enabling the user to hear his surroundings

Key results
- The production costs of the smart earpiece will be around €60. If the device will be produced and sold by a supplier, the cost price will be around €150 to €200.
- Investment needed for creating the app will be around €22.000.

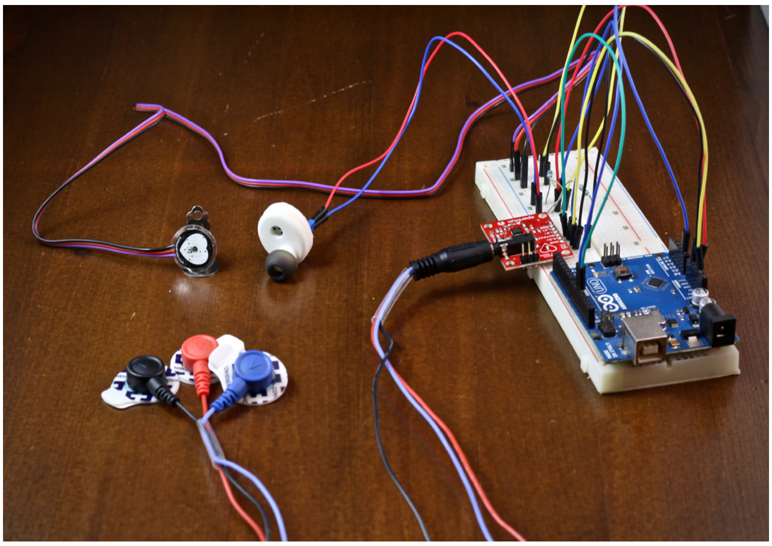


Figure 50. Left: clay and 3D print models for the form study. Right: working prototype

Source: Brandweer Nederland

6. VALIDATION OF THE CONCEPT

1. **Approach**
2. **Feasibility**
3. **Viability**
4. **Desirability**
5. **Recommendations for future developments**
6. **Requirements**
7. **Conclusion**

This chapter describes the feasibility of the concept in terms of realization, usefulness and if it fits in the firefighting culture (the needs of people, the possibilities of technology, and the requirements for business success). Does it adds an extra value to the fire department? It concludes with recommendations and a list of requirements for the development of the product.

Approach

The validation of the concept is based on the three pillars of the most valuable design defined by IDEO (Brown, n.d.). When these three are well addressed in the new design solution, it would increase the value of the innovation. The three pillars are:
Feasibility - Is it technically possible?
Viability - Does is has enough business value?
Desirability - What does the user want?

For validating whether the new concept meet these requirements, the main assumptions on which the concept is based are plotted in a validation board, see figure 51. These assumptions are used to validate the feasibility, viability and desirability. The outcome of these validation, resulted in recommendations and requirements for future development.

A validation board is a tool which helps to map out the core assumptions of a business proposal. When the riskiest assumption (the assumption that will cause the business to fail when invalidated) is invalidated, a pivot (change the customer, problem or solution hypothesis) needs to be made in order to ensure the project will succeed (Lean Startup Machine, n.d.).

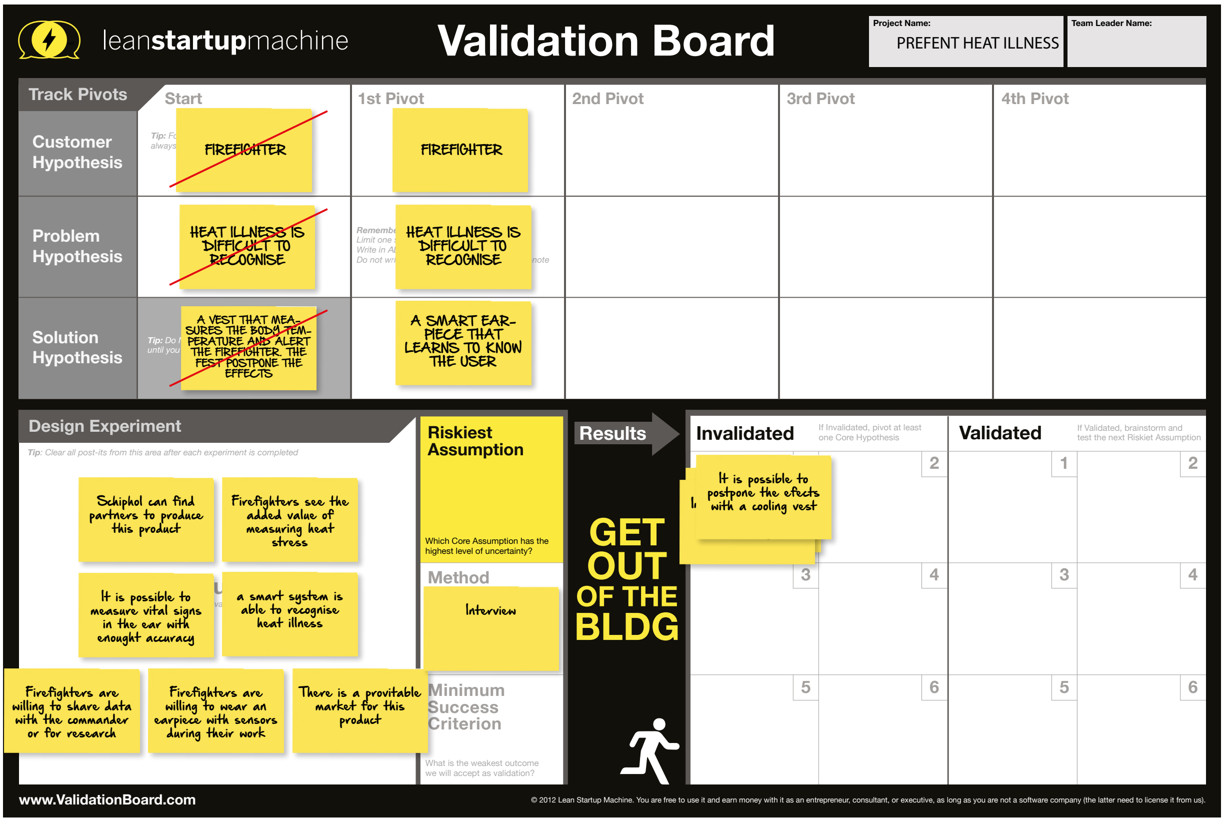


Figure 51. Validation board for the QuantiFire system

Figure 52. Test in Erasmus MC with a holter monitor.

Feasibility

To validate the technical feasibly the following assumptions are tested:

- It is possible to measure biometric data in the ear with enough accuracy
- A smart system is able to recognise heat illnesses

Most of the technology used in the QuantiFire concept is proven technology: pulse sensors are being used for heart rate measurement in both medical as home applications, IR temperature sensors are used in ear thermometers already, and smart earpieces are widely available on the market as well (Van Hooren, 2016). However, two things are not proven yet: blood pressure can be measured around the ear and the software of the system is able to predict heat illness based on collected data. To answer this, a test is performed and a data scientist of Schiphol is interview.

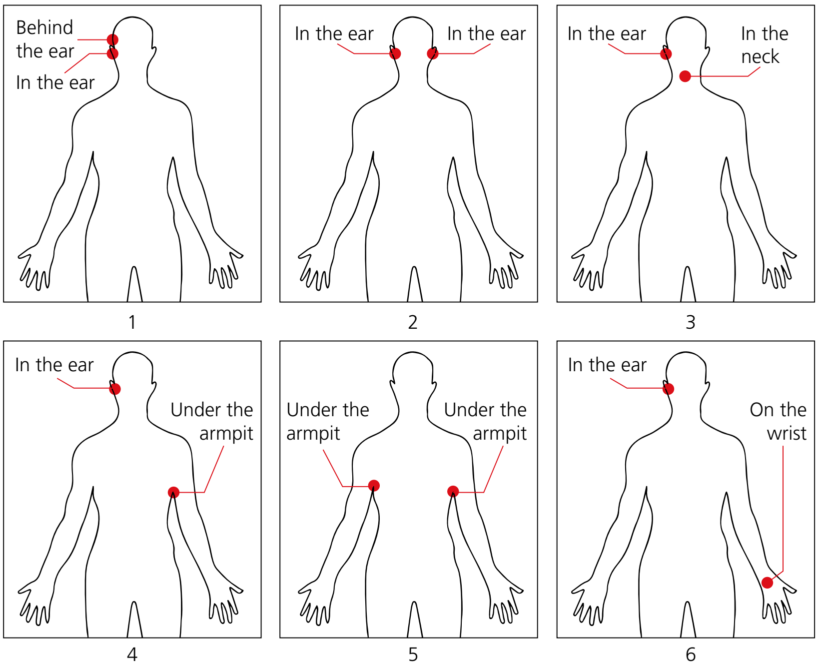


Figure 53. Test in Erasmus MC with a holter monitor.

Blood pressure

Introduction:

The most promising technique to measure the blood pressure around the ear is by using a combination of a PPG and a ECG measurement. As mentioned before, these two measurements could provide the pulse transit time which is correlated to the blood pressure. A PPG can easily be measured around the ear, however, an ECG is normally performed with sensors on the chest. Therefore a test is done at what places an ECG gives sufficient results.

Method:

The test is performed at the Erasmus University Medical Center in Rotterdam at the department of cardiology. During the test a portable ECG device (a Holter-monitor) is used, see figure 52.This enables walking and other activities during the measurement, which simulates the work of a firefighter. From the holler monitor only two electrodes are used which are placed according to the locations in figure 53.

Results:

The results of this test (figure 54) shows that a ECG in one ear and in two ears does not give a usable diagram. The peaks are unrecognizable. One electrode in the ear and one in the neck does results in a diagram with a lot of noise, but the peaks are recognizable. Measurements under the armpits or on the wrist and in the ear results in a really good diagram.

Conclusion:

The test shows that in order to measure the blood pressure, the smart earpiece needs a neck strap or a separate device. Since the two electrodes needs to be connected by wire, the best solution would be to integrate the electrodes in a shirt on the location

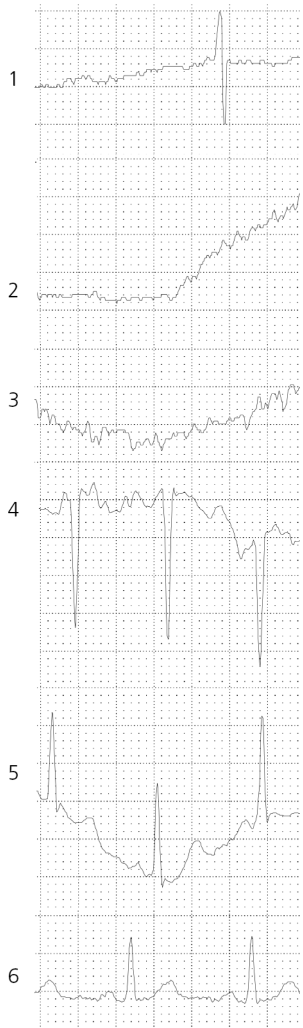


Figure 54. Results of the ECG test

of the armpits. A neck strap is not convenient for firefighters because it will interfere with their jacket.

<u>Software</u>
To know how to use data analytics to predict heat illness from physiological data, Rok Mihevc, a data scientist at Royal Schiphol Group is interviewed. The full transcription can be found in appendix [A-SRM]. The outcomes of the interview are described below.

Mihevc indicated that in order to say whether it is possible to predict heat illness from physiological data, first a large amount of data needs to be collected. A good dataset for doing analysis would be about 50 till 100 firefighters with 50 sessions per firefighter who gets some heat illness symptoms for at least 2 times. This data can be used for data analytics.

Anomaly detection is for this case the most promising data analytics technique. With anomaly detection, which is often used for fraud detection, patterns can be found in time-series data (Wikipedia definition: a series of data points indexed in time order).

The way anomaly detection works: An algorithm needs to be written that abstracts a pattern in time from the time-series data. The algorithm learns to know what are the normal conditions. If something changes, a value rises for example, the algorithm will notice that. Then a threshold will be set on the point that indicates a problem. With new data, the baseline will be rectified and therefore improve the analysis.

Because heat illness is not generalisable among many people, different models need to made based on a personal profile. Next to that, the collected data needs to labeled, this means that it is important to know when heat illness occurred. This could be solved when firefighters are logging their activities in an app.

Another option for processing the data is by letting doctors describing what exactly happens during heat illnesses and make a model out of that. An algorithm can be written based on this model. However this is really complex and difficult when people reacts differently on heat.
A possible solution for that is to let firefighters perform physical stamina test and develop profiles based on these test. Based on this profiles it is possible to say when a person reacts on a certain condition. These profiles does not need to be discreet, it could be made as continuous sequences.

However the most important thing to do first is to collect data. A first step could be to collect some data from a few firefighters over a short period, and artificial multiply this data. With that, it is already possible to know how big the chance is that the larger dataset will give positive results.
Other ways are to find free available data online. This could be data from for example marathon runners. These datasets could be found on websites like kaggle.com.
On kaggle.com it is also possible to run a competition or challenge for your data. Other people will then try to find patterns, with which they can win prices. This could be an option for developing the software or to find other cases to learn from.

The assumptions that need to be tested with the collected data are:
› The symptoms are not the same for different people.
› If it is possible to get precise enough data
› That the amount of signals enables to predict heat illnesses.

Conclusion:
The interview didn’t validate nor invalidate the assumption. There is a possibility that it is feasible, however, this can only be validated after a test period in which data is collected.

Viability

To validate the business value the following assumptions are tested:

- Schiphol can find partner to produce the product.
- The product brings added value to the firefighters work environment

To investigate wheter the fire department of Schiphol could team up with other parties, both Dräger (one of the main suppliers of Schiphol) and IFV (research institute) approached). During a meeting with them, their view on this concept is investigated and they are asked wheter a co-oporation would be a possibility. A market study is performed and the Business Model Canvas including the Value Proposition is created.

Figure 55. Possible collaboration

<u>Partnership</u>

It is not Schiphol's intention to produce an earpiece for their firefighters. For developing the smart earpiece they need to collaborate with a supplier and a research institute. The combination of these three parties could consist of Dräger (the current supplier of the breathing apparatus) and IFV (the physical safety institute). Both Dräger and IFV showed interest in the concept.

For Dräger, in this case represented by the Business Unit Manager VT Patrick van Vugt, this could be interesting because they need to be working on more innovate projects. Dräger doesn't have the capacity to work on a lot of innovative projects, but they need to innovate in order to survive. Their market is changing and competition is growing, innovation keeps them competitive. An collaboration with other parties would enable them to get more room for innovation.

Heat illness is a topic that often emerges according to van Vugt, but it is never researched in a serious project. Dräger has a large medical department, that makes heat illnesses an interesting topic for them.

Van Vugt also sees the moral obstacle of this concept. For example if the firefighter is saving a victim and the system indicates there is potential health risk for the firefighter. What would be the best decision: saving the victim or saving yourself? It is a difficult moral dilemma especially when insurances companies are involved. It is similar to the self driving car where the car needs to decide between two evils: killing two passengers or five pedestrians (Bonnefon et al., 2016). Therefore, according to van Vugt, it is important not to focus on achieving the main goal directly, which is developing a full monitoring and warning system. First some steps needs to be made in order to make this possible. A first step could be to develop a device with a short term value like a better communication system and using data collection only for training purposes. The next steps could be: doing more research on the effect of heat stress and use this to send out a wakeup call to the market.

IFV, in this case represented by Eric Mol, has a market driven-approach. They do research when there is a research question from the market. This is often when something bad happens. Only rarely would they perform research initiated by themselves. Therefore in order to include IFV, a collaboration between Schiphol and Dräger would be necessary.

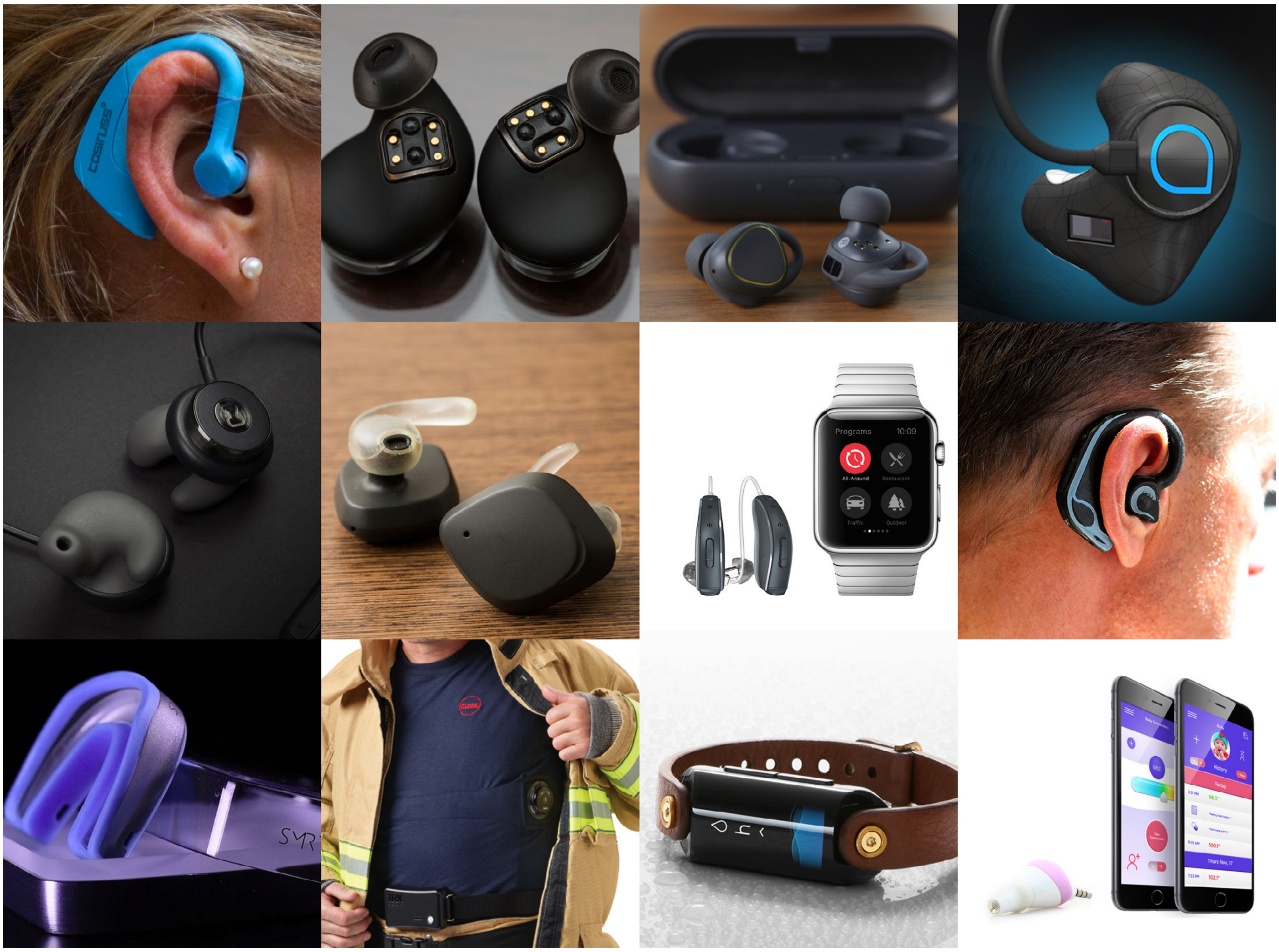


Figure 56. Products from market study. Topleft to bottom right: Cosinuss One°, Bragi Dash, Samsung Gear IconX, Aware, Revols, Elbee, ReSound Hearing Aids, FreeWavz, SMRT MOUTH, WASP, LVL, Tympani Smart Thermometer.

Market study

A market study identifies the current solution existing on the market. This helps to know the competition, gain inspiration and to be able to make the new product distinctive.

For the market study, twelve products are researched that are correlated to this project, see figure 56.

Hearables (smart hearing devices) are emerging, a lot of companies, ranging from headphone to hearing aid producer are investing in this new development (Wesley Banks, 2017). Essentially, hearables are wireless earphones with a microcomputer inside. Most hearables on the market are focused on sensing biometric data, improve the interaction with hearing aids and on bringing smart capabilities to the ear (e.g. live translation and augmented hearing). Although there are hearables with all possible sensors there is not one that combines a custom moulded earpiece with the sensors needed for recognising heat illnesses together with a smart communication device. For example the Cosinuss One ("cosinuss°", n.d.) measures the core temperature and heart rate only, the Bragi Dash ("Bragi", n.d.) only measures heart rate together with improved hearing abilities and better communication, the Aware ("The Aware", n.d.) and the Revols ("Revols", n.d.) are custom moulded earpieces for sound only. There are however other products that are focused on heat illnesses, like the SMRT MOUTH ("SMRT MOUTH", n.d.) a smart mouth bit that measures biometric data and the LVL wristband (LVL, n.d.) that measures the hydration.

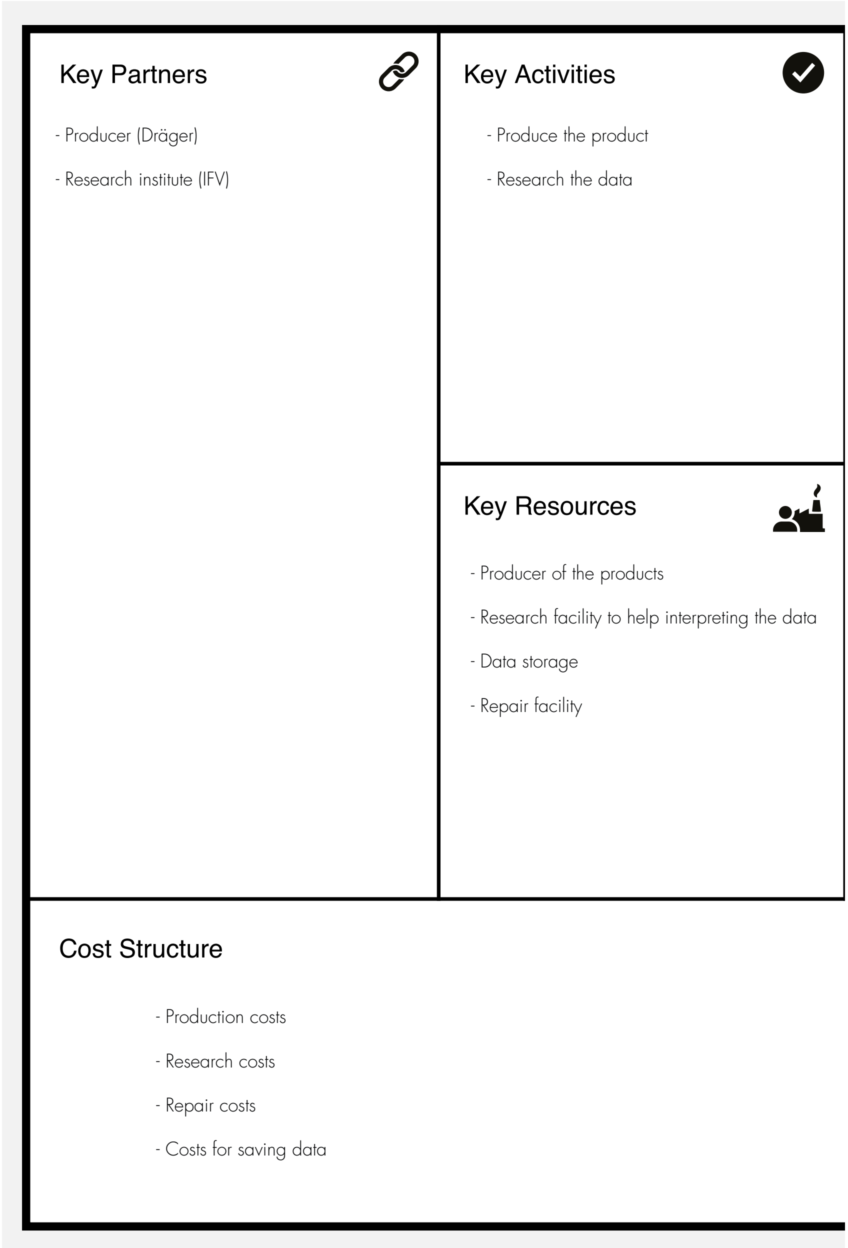


Figure 57. Business Model Canvas for the QuantiFire system

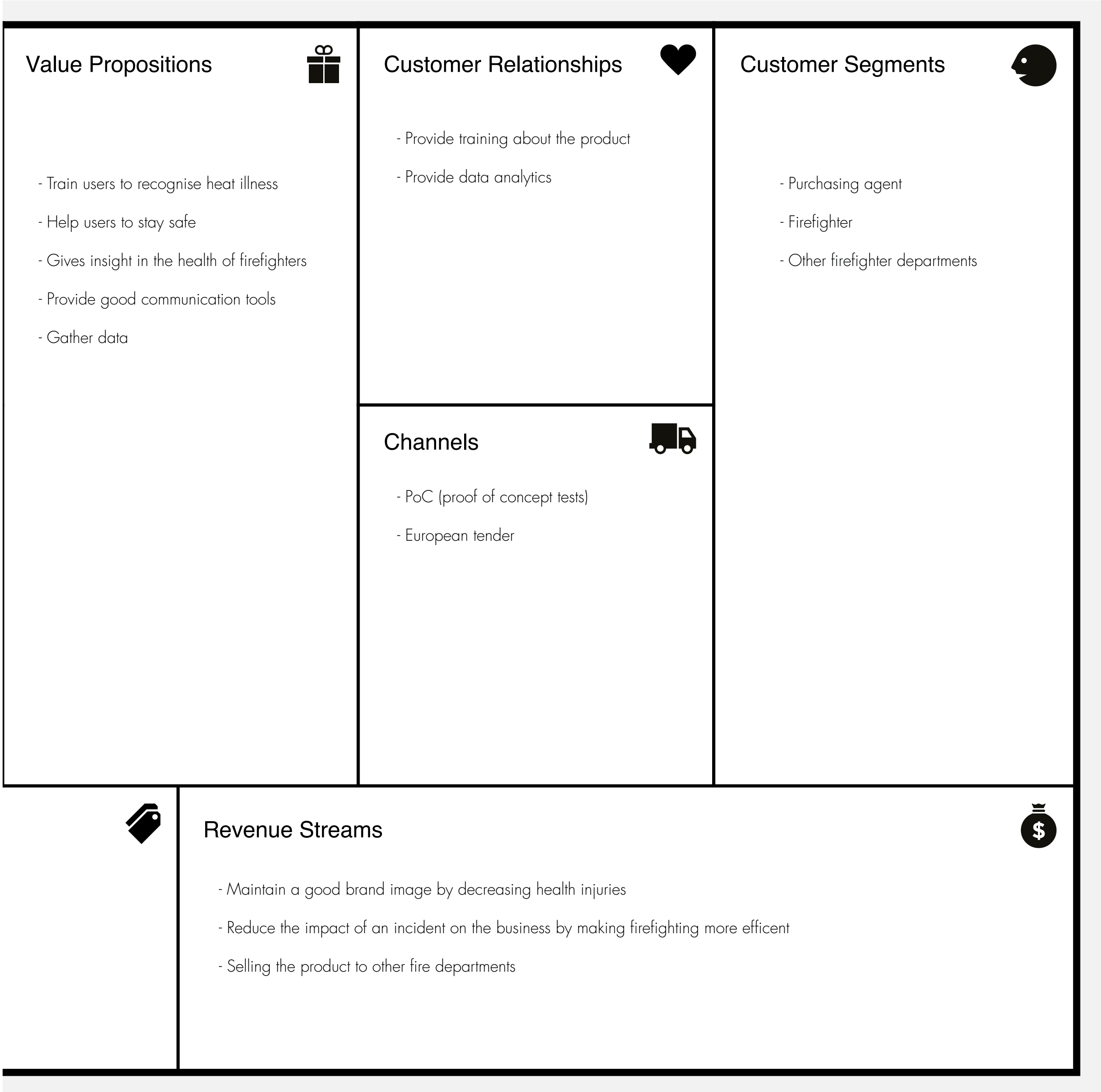
Business Model Canvas and Value Proposition

To gain and retain a successful product, not only a good working product is needed, a good business model is really important as well. A business model helps to explore who the customer is, what value the product offers for this customer, how the customers can obtain the product, how to remain a competitive advantage and what the revenue and costs would be (Osterwalder et al., 2015).

Figure 57 shows a Business Model Canvas (BMC) for the smart earpiece from the perspective of a new startup. It is not known yet who will produce and sell this product. It could be Schiphol, a producer like Dräger or even a startup. By choosing the perspective of a new startup, it is possible to fill in the BMC without being bound to a specific company.

A sustainable business model need to meet the customer demands in order to survive. Therefore it is important that the Value Proposition (VP) fits the customer segment in the BMC. When the features of the VP match the characteristics of the Customer Segment, there is a problem solution fit. A product market fit is achieved when the market validate this match (Osterwalder et al., 2015).

Because the customer segment of the concept consists of the firefighters themselves (the user) and the purchasing agent of the fire department (the buyer), a VP is necessary for both. Figure 58



on the next page show the value propositions for both the purchaching agent and the firefighter.

Addressing all the pains and gains with a product or service is not always possible and not necessary as well. It is more important to focus on the ones that make a difference (Osterwalder et al., 2015).

Value proposition for the purchasing agent

Pains

Difficult to monitor the health of the personnel - The device makes it possible to track the health of the firefighters and save the data for analyses.

Difficult to know how to make firefighting more efficient - The device gathers data, in this case health data, this enables calculations and analysis for a more efficient use of the personnel. It is also a start for collecting data of the fire brigade. It can stir the demand for more data analysis in other fields as well.

Firefighters are critical about the equipment - The device is a personal fit, this will make it comfortable to wear. Furthermore, the device should work well and should not disturb them from their jobs. This can be solved by making a good design.

Firefighters have a resistance towards new products - The device will work as a normal earpiece for communication as well. Therefore it is a replacement of something they already use.

Personnel don't like to share privacy sensitive data - This is not solved yet. Firefighters worry that they can got problems with their boss when the data shows them they are doing something wrong. That is because making mistakes is not (yet) accepted. According to Arjan Bruinstroop (operations manager at the fire department) this culture is already changing and people become more and more aware that making mistakes is not a problem because you can learn from it. It needs some time before firefighters can really trust that sharing their data is a good thing.

Gains

Get appreciation from firefighters - When the product fits the firefighters needs, this can result in appreciation towards the purchasing agent.

Good trained personnel - The product helps firefighters to train themselves by knowing the limits of their body and therefore make them better firefighters.

Healthy firefighters - The data gathered with the device, helps the firefighters to know how to improve their health and to prevent cardiovascular injuries from happening.

Value proposition of the concept

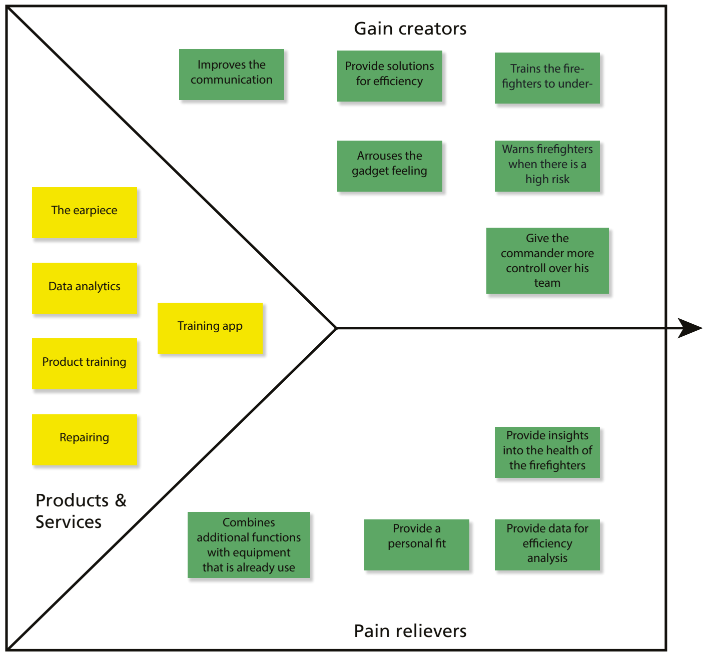


Figure 58. Value proposition for the QuantiFire system

Value proposition for the firefighter

Pains

Losing the job because of making a mistake - This is discussed before. It is not solved yet, but it needs time.

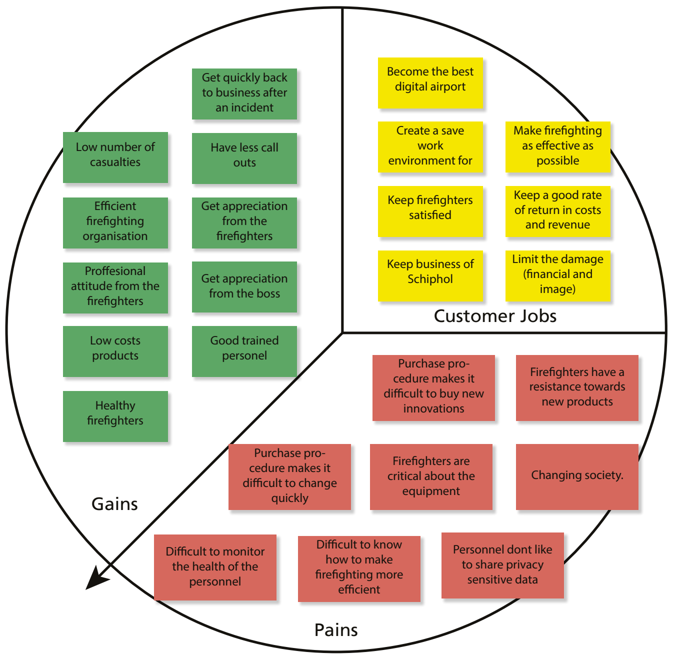
The work environment is not healthy - The product does not solve this problem directly, but it helps firefighter to cope with the situation in order to stay healthy.

Difficult to communicate during a deployment - The product provides an improved communication device.

Gains

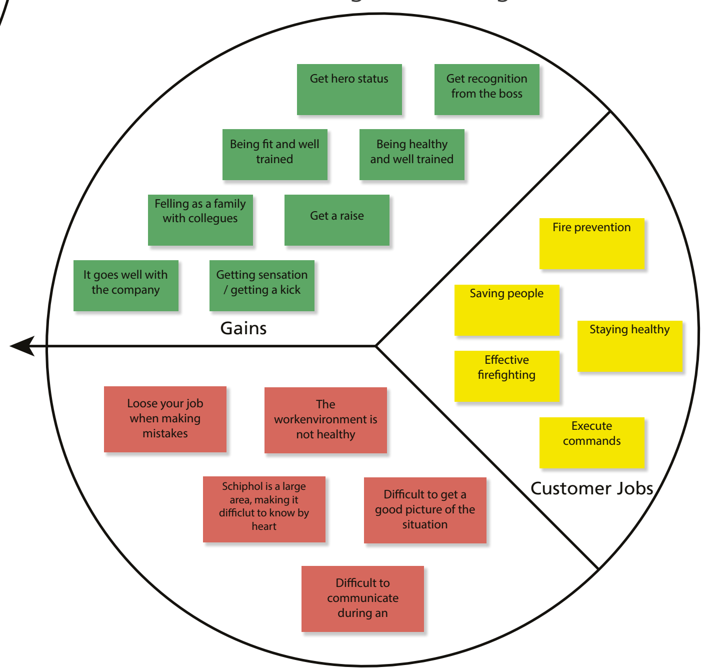
Being fit and well trained - As said before, the product does adds to the training of firefighters becoming better.

Likes to use hightech products - The product includes new technology and gives it a gadget status.



Customer segment purchasing agent

Customer segment firefighter



Desirability

To validate the concept on the human need the following assumptions are tested:

- Firefighters see the added value of measuring heat stress
- Firefighters are willing to share data with the commander or for research
- Firefighters are willing to wear an earpiece with sensors during their work

Three sessions are performed with firefighters to answer the question wheter the concept fulfil the human needs. The first two sessions are performed during firefighting exercises. The last session was a user test with the prototype.

Test sessions

The Cosinuss One earpiece is used to test the concept. It measures temperature and heart rate but does not provide audio. The test was split up in two experiments. The first one, performed during a firefighting exercise at Schiphol, was focused on whether firefighters are willing to wear an earpiece that measures certain vital signs and what requirements they have for a smart earpiece. The second one was to measure data during realistic fire exercises and to find out if measuring heat illness would be of added value for the firefighters. This was performed at the training facility in Wijster, The Netherlands.

Results:
The first experiment shows that the information of the biometric data is interesting to firefighters. They indicated that it is like a confirmation of what they feel and that it could help them to prevent heat illnesses. About the Cosinuss One earpiece itself they were less satisfied. It took too long to put it in. Besides that, the earpiece reduced the hearing ability. During a deployment it is important to hear the surroundings, therefore the device should not affect the hearing ability. They indicated that if the device would be combined with a communication device, it would be a good solution.

The second experiment gave insight in what happens during real deployments. Remarkable was that none of the six participants complained about the Cosinuss One earpiece. They indicated that they didn't feel it and they didn't complain about the loss of hearing ability. The data showed, [A-DOT] that the temperature of most participants stayed between 36°C till 38,5°C. Only one of the participants reached 39°C, although he didn't feel it during deployment but later indicated that he felt the first symptoms of heat illness.
The participants indicated not to have any objection in sharing the data with their commander and for research. They said that it is for their own health.

User test

Because it is important to get feedback from the intended user, a user test is carried out at fire station Rijk at Schiphol. This user test was focused on testing the interaction, aesthetics and added value of the concept. The goal is to gain insights for recommendations and requirements for the for further development.

Method:
The test is carried out with 7 firefighters, one commander individually and 6 firefighters in a group. The concept was explained to the participants and they got to see and hold the mockup of the earpiece and the prototype of the QuantiFire app.
Next, a discussion was started about the concept on the basis of certain questions.

The questions included, what they think about the concept at first sight, if they are willing to use this concept, how they would use the product, what they think of the added value of the concept, what they are missing in the product and what are the flaws.

Results:
The answers from the commander was remarkably different from that of the group of firefighters. The firefighters where more enthusiastic about the concept and didn't see the flaws the commander indicated.

Figure 59. User test at fire station Sloten

The commander questioned what would happen if you lose the earpiece, or forget it to bring to work. That would mean a firefighter could not be deployed. He also doubted whether firefighters are willing to perform the extra action of putting in the device. He said, this would depend on whether they think is adds a significant value to their work. The group of firefighters was more positive about this. They indicated that the same applies to the radio, that could also be lost or forgotten. They really saw the added value of the product and were therefore willing to perform the extra action, which is just a matter of getting used to it. The most important added value they saw about this concept is the improvement of the communication. If the device helps communicating better through the radio and in noisy environments, they would already use the product. Moreover, this earpiece enables them to communicate without the need of wearing their helmets. The function of a device that keeps track of their health and warn them in case of a risk, is less important than the communication part, but they all indicated that it adds value as well. They are aware of the risk of their job, therefore they are willing to use a product that helps them to prevent injuries. However, they questioned what the effects of this product will be in the long run. It could make them dependent on the technology. Therefore it is important to incorporate that during training.

Although all firefighters indicated that the appearance of the product fits the style of their work environment, they had some remarks about the size of the product. They were wondering if the device could be made smaller to fit completely in the ear. When the device sticks out of the ear, they are afraid it would not be comfortable to wear it under the helmet. Besides that, some firefighters indicated that it takes some time to know how the device should be put in the ear, this time could be decreased by clear indicators.

The charger case is designed to be installed into the firetruck. However, firefighters indicated that it is possible that a person is assigned to two different firetrucks. Therefore it would not be convenient to always have the device in the truck.

Another concern was data sharing. Firefighters are afraid that the information about their health could have a bad influence on peoples careers when their employer could have access to this data. They indicated that the same applies for their health tests. Every half year, firefighters have to perform a health test, which they have to pass. Their employer only get to see the results whether they pass the test or not. They have no access to the exact results. This data is only shared with their doctors. This could also apply to the health data collected by the QuantiFire system. An evaluation of the data by the system could be shared with the employer and the detailed data will only be shared with the person in question and the doctor. Firefighters indicated they had no problem with sharing the data with their commander or driver at the moment itself. They also suggested to set an expiration date to the collected data.
This concern also meant they didn't like the fact that firefighters could share their data with other firefighters in the app. This would lead to competition within the group, which would only be beneficial for the most sportive and healthiest of the team.

Recommendations for future developments

The product as described in chapter five is the result of a preliminary concept design process. It is detailed in a way that it can be tested with the user and in order to discuss the project with the board of the fire department for potential investing. From the user test and conversations held with other firefighting related people, a few recommendations can be made.

The recommendations include:

› Extension of the system with more sensors
› A smaller and better visible design
› Improvement of the communication system
› Sharing the data with the commander or driver
› Improving the interaction
› Other improvements

Extension of the system

The earpiece is designed to gather heath data to predict the risk of injuries. Therefore the more different data is available, the better the prediction can be made. The current smart earpiece contains the measurement of the core temperature and heart rate. According to the analyses of the firefighters' health in chapter 4, this is enough data for making preliminary predictions, however, blood pressure, sweat rate, sleep and hydration would be a huge improvement. Therefore it is recommended to put effort in the development of these sensors in the smart earpiece or in other devices that can be connected to the system. For example blood pressure can be measured using a shirt with an ECG sensor and breathing rate can be added to the system by the breathing apparatus. Moreover, it will be beneficial if users data is measured as much as possible, not only during their work. Therefore it is possible to open up the system for consumer products as well. Examples are health tracking wristbands, or music earphones with biometric data measurement.

Design of the device

A big concern from the users is the size of the earpiece, in order to be worn comfortable under the helmet, the device should be as small as possible. To achieve this, the buttons on the device could be removed. The volume buttons can be replaced by a function in the QuantiFire app and the power button can be replaced by a smaller button or turn the device on automatically when it is taken from the charging case.

Furthermore, the orientation of the device is still an issue. The current design already suggest how the device should be worn through the shape of the shell. However this could be emphasized more with clear indicators of what the top and bottom is.

Another small improvement of the design includes making the device more visual in dark surroundings. Therefore fluorescent material can be used for the housing.

Improvement of the communication system

The potentials of the smart earpiece in improving the communication between firefighters are great. Not only can it provide a clearer sound by enhancing voices and decreasing noise from the background, the way people can communicate with it could be improved as well. Because the smart earpiece is a small computer worn in the ear, it could eventually replace the traditional radio. This would remove the hassle with wires, which firefighters are facing, by making the system completely wireless. Furthermore, the device could use smart solutions. For example the device could recognize when the user is talking and automatically send that to the others in the team. Another option is using a voice command to start a conversation. This also enables the use of different channels (this is especially important for the commander who has to communicate with different teams). By using a voice command the user can then choose the right channel. Also the most important channels can get priority over other channels, conversations from other channels will be hold back or played in a lower volume.
For normal firefighters it is currently not possible to listen to the radio channel of the commanders, although this information could be crucial to them. Now the commander is responsible for forwarding

Figure 60. Player fitness bar in the FIFA video game

that information, which is easily forgotten in a hectic situation. The smart earpiece could solve this by enabling firefighter to listen to this channel without the ability to say something to it. Another possibility is the ability to replay previous conversations, this would eliminate the need to ask for repetitions.

<u>Data sharing</u>

The warning system, as it is designed now, is focused on the user. Only he gets a warning by a computer voice. As stated before, it could be beneficial if the commander could see the health status of his crew as well. This could be implemented in the MOI system that the firefighting department of Schiphol is currently developing. However, this should be implemented in the least distracting way. For a commander, it is only necessary to know if a firefighter is at risk and should be called back or saved, or for choosing who to deploy for a certain task, who is the most fit and has made the least exertion. An example which can be used for the development of this feature is the player fitness bar in the football video game FIFA (figure 60). This bar shows the current fitness of all players and decreases as the player is more exerted.

<u>Other improvements</u>

Because the smart earpiece is custom made for all the users, it is more expensive than a standardized earpiece. Moreover, it makes it impossible to swap or share devices. This could be a problem if the smart earpiece is broken or lost. A possible solution could be a modular earpiece. The custom made part will be made as simple and cheap as possible. This will be the part a firefighter always needs to carry. The other part, with all the electronics, would only be added to the custom made part by the user, just before usage. Because this part is standardized, and can be used by everyone, it is only necessary to invest in the amount of devices that are used at one moment. Furthermore, every firetruck could always have the right amount of devices in the charger.

To solve the problem of running out of battery during a deployment, it is possible to develop a wireless charging module in the helmet. This however needs a battery, which will significantly increase the weight of the helmet. New developments in battery technology could solve this problem.

The current charging case is designed to be installed in the firetruck. This could cause problems when firefighters are assigned to different fire trucks. Possible solutions for this are a mobile battery case that can be carried the whole day or the device should be able to run the whole day on one charge and to be charged at night in the room of the firefighter.

Other things that need further development are, the way the feedback is provided by the computer voice and the settings of the device in the QuantiFire app.

Requirements

1. Sound
   1.1 Integrated speaker generates understandable sound of voices
   1.2 Play sound from the radio on integrated speakers
   1.3 The device should not decrease the hearing ability of the user
   1.4 Record sound with a quality that is understandable for voices
   1.5 Increase vocal sound and decrease noise to an understandable sound

2. Measuring
   2.1 Measure core temperature with 0.1°C accuracy
   2.2 Measure heart rate with 1 bpm accuracy (Eric Mol)
   2.3 Measure blood pressure with 20 mm Hg accuracy
   2.4 Detect movement
   2.5 Detect when product is placed in positionn

3. Alerting/training
   3.1 Calculate the risk level of heat stress in the body based on the sensors input
   3.2 Indicates how much the health is at risk in a non disturbing way
   3.3 Provide a warning when the health risk is critical
   3.4 Provide a clear visual of the collected data
   3.5 Show health data to the commander in a non disturbing way

4. Interaction
   4.1 The product should be ready for use within 10 seconds
   4.2 Correct orientation of the device can be recognized
   4.3 It should not be possible to accidentally change the settings while wearing the device
   4.4 Speaker volume can be increased or decreased without the need of smartphone app
   4.5 It should be possible to change the moment of the warning based on a risk level
   4.6 Risk level calculation should be improved with new data

5. Ergonomics
   5.1 Earpiece fits comfortably in the ear for at least 6 hours
   5.2 The sensors should always be in the right position

6. Safety
   6.1 Malfunction should not cause injuries to the user or others
   6.2 The radiation from the device should not be a risk for health
   6.3 The device should not cause hearing loss
   6.4 The device should not reduce the skills of the firefighters

7. Performance
   7.1 The device works on a battery supply for at least 6 hours
   7.2 The device should resist a drop from 3 meters height
   7.3 The device should stay in the ear in case of extreme movement
   7.4 All parts of the device communicate over a stable wireless connection

8. Environment
   8.1 The device is waterproof
   8.2 The device resists a temperature over 40°C

9. Lifetime
   9.1 The device should work for at least 3 years

10. Maintenance
   10.1 The device can be cleaned by the firefighter

11. Production costs
   11.1 The device can be cleaned by the firefighter

12. Design language
   12.1 The design language of the product should make firefighters confident enough to wear the device

13. Materials
   13.1 The materials of the device should be comfortable to touch the skin
   13.2 The materials of the device should be allergy save

14. Dimensions and weight
   14.1 The size of the device should fit under the helmet
   14.2 The weight of the product should be comfortable to wear in the ear

15. Social implications
   15.1 The device should not break with personal values
   15.2 The device should be accepted by society

Conclusion

The three pillars, feasibility, viability and desirability are all dressed in the validation tests and interviews. Although this validated most of the assumptions, it is questionable if this gives a good impression of the reality. During an interview people tend to accept things quickly. Firefighters indicated not to have a problem with sharing the data with their commander, they are willing to wear an earpiece that measures biometric data and they saw the added value. However, this was all based on a story about the final concept. They weren't able to use the device. Their answers could be different.
The assumptions whether it is possible to create a smart system that can predict heat illness and that it is possible to measure accurate data around the ear are neither validated nor invalidated. The interviews done give insight in whether there is a possibility that it will be validated. This indicates that more tests needs to be done to fully validate the concept. However, it resulted in the recommendations and requirements which can be used in the next stage.

Key results

- The device should have a short term values (e.g. improve communication system)
- The device should not reduce the hearing ability
- Blood pressure cannot be measured around the ear. A neck strap or separate device (e.g a connected shirt) is needed.
- Firefighters have no objection in sharing the data with their commander
- A large amount of data needs to be collected for performing data analytics. (50 session from 50 firefighters with symptoms of heat illness)
- Anomaly detection seems the most promising data analytics technique.
- Recommendations for future development are: the extension of the system with more sensors, a smaller and better visible design, improving of the communication system with more smart features and enabling to sharing the data with the commander or driver.

Source: own photo

8. CONCLUSION

This chapter concludes the project by looking at the overall results, the consequences of the design proposal and it will discuss the next steps for future development.

Project results

The goal of this project was to make the fire department of Schiphol more safe and efficient with smart technology. After an extensive analysis of the firefighting current and future context, five design directions for smart technology solutions remained. All these five direction are interesting directions for the fire department. Because this graduation project had limited time and capacity, only one, or eventually a combination of two directions was chosen to continue with. However, it is recommended to look into the possibilities of the other directions in the future.

The direction Virtual Assessment, which was chosen as the main direction for this project first, been continued by employers of Schiphol. After a validation tests performed for this project, see appendix 4, firefighter commander Ian Downing looked into the possibilities of continuing that idea. However, due to political obstacles (it is not allowed to wireless stream security camera image from Schiphol), the development is currently temporarily stopped until new developments in the political situation.

Apart from the fact that this direction is not continued at the moment, it shows that this graduation project has an effect on the company as well. It stimulates employees from Schiphol to work on new innovative projects, which is also one of the goals of Schiphol NeXt. In this case, Ian Downing is already working on other innovation projects and has participated in the Innovation Bootcamp organised by Schiphol Next. Hopefully it will stimulate other firefighters as well.

Next the effects of this project on the fire department, this project could also be helpful for Schiphol NeXt. The design methods performed in this project could serve as inspiration for the employees of Schiphol NeXt. Schiphol Next has embraced the agile methodology Scrum for their projects. This methodology is developed for software development and cannot be used one-to-one for product development. This project shows how user centered design and design driven innovation can be combined with agile methodology, by the quick and simple tests that are performed after a more intensive research.

The design direction that is finally chosen for this graduation project, ‘the firefighter’s health’, has let to a detailed concept proposal of a smart system for firefighters. This system helps to prevent heat illnesses among firefighters and it has the potential to improve the communication between firefighters during deployment. Therefore this product could increase both the safety and efficiency of the firefighters, which was the main research question of this project.

The learnings of the case study in chapter one, showed that in order to make a project at the fire department successful, it is important to solve small problems at the time, that the first implementation does not have a lot of technical problems, that there is a clear roadmap after a student project has stoped and that the concept does generate value for the firefighters.

Although, the concept started small with only solving the heat illness problem, it eventually addressed the communication aspect as well. In the future there are even more possibilities with the system. It is important that the further development of this concept is focused on only these two aspects first otherwise it will become

to complex. Next to that, it is important to focus on the technology aspect as well. This is not yet elaborated in the current concept. However, all technologies used, are validated technologies.
As pointed out in chapter six. The proposed concept does generate value for firefighters. Especially when it is focused on the communication aspect.
To enable the fire department to continue with this project, a roadmap is created. This roadmap, the next steps, is described later in this chapter.

The consequences

This projects investigated the possibilities of smart technology for the fire department, but next to the possibilities, it is also important to look at what the consequences are of this technology. What are the ethical, societal and personal consequences the fire department will face if they embrace smart technology? Because it is impossible to know the future, we don't know if these consequences will occur, but it is important to think about it in order to be able to move the development in the desired direction.

Smart technology is designed to make the life of human beings more easy. It takes away the need for human beings to think about certain things. In a lot of cases, the computer can even make better decisions than a human being can do, for example in diagnosing cancer (Steadman, 2013). This is related to the fact that a computer, especially when connected to the internet, has access to a wide range of knowledge and a huge computing power. Because humans always strives for the most efficient way to perform a task, people will no longer try to perform certain actions without the use of a computer. This results in the loss of certain skills because they are no longer trained and thus disappear. The same already happened with the people's skill to navigate with a paper map.

The same thing could happen with smart technology for firefighters. When a smart system provides a significant added value in performing the job of a firefighter better then they can do themselves, a firefighter will rely more and more on that system. In the case of this project, the QuantiFire system has the potential to accurately predict when a firefighter will get a heat stroke and warn the user before that happens. Firefighters will eventually trust the system completely, when the predictions are good every time. Thereby he will lose the ability to make an assessment of the potential health risk himself. This could cause dangerous situation when the technology fails.
Therefore, it is really important to train the firefighters how to use this product, and always try to assess the situation themselves. The same happened with the thermal image camera's. When they were first implemented, firefighter would use them to navigate in dense smoke constantly. But because of that, they lost the conscious of their surroundings (van Brug, 2017). Therefore they trained themselves to use the thermal image cameras only when it is necessary.

On the other hand, it is questionable whether the technology will fail and if this will be worse than not having the technology. Of course, according to murphy's law, if technology could fail, it eventually will, and that could cause serious danger. However, what if the technology makes firefighting in general more safe? It is the same debate as what is currently held about the self-driving car. According to Bob Lutz, former General Motors vise charman, self driving cars are safer than a human driven car (Fox, 2014). A self driving car is not 100% safe, but will make significantly less mistakes than a human being will do. Therefore the total safety will increase.

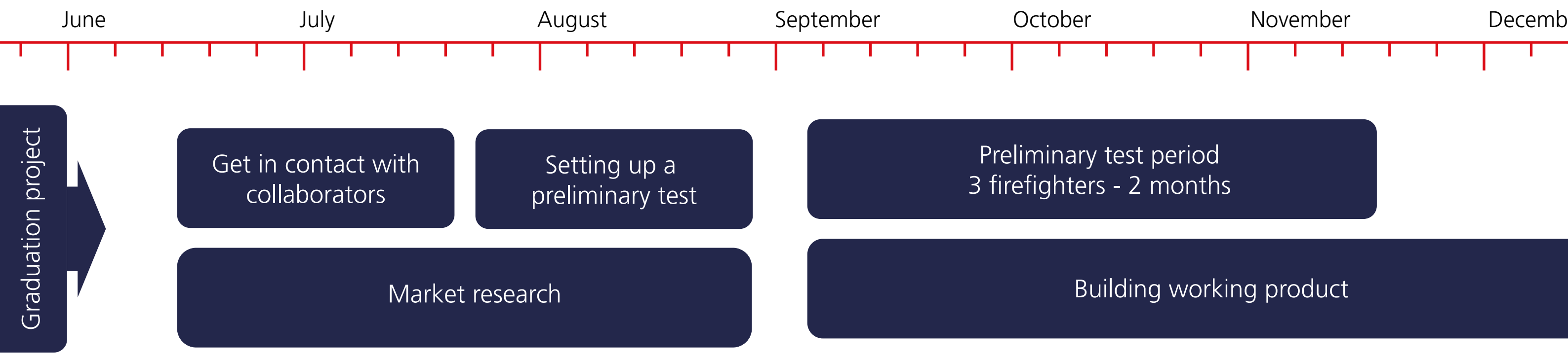
According to Yuval Noah Harari (2017), the next big revolution in history will not change the world outside the human being (the nature, the tools, the society, the economy), like what happened in the big revolutions before, the next big revolution will change the human being itself. The new goal of human kind will be manipulating and controlling the world inside the human being. One danger that Harari indicates of this revolution is that humans will do the same to the world inside their bodies as what they did to the world outside them. They used their control to completely destabilize the system and now planet earth is on the brink of an ecological breakdown. "Humans just don't completely understand the complexity of the world and they were not responsible in how they behave" Harari stated. The same could apply to the world inside the human being. There is still a lot that humans don't know about their bodies, and manipulating it could completely unbalance the internal ecological system. Of course, the QuantiFire system as it is designed in this project, does not change anything in the human body, but it could be seen as a first step towards this development. When firefighters are getting used to smart technology that helps them to survive better than they could do without the technology. The trust in smart technology will grow and therefore the step to use this technology for their internal body is much smaller.

Besides tth potential societal dangers, there is a risk for the privacy of its users as well, as stated in chapter six. The data of the physical health of the firefighters is measured and therefore there is a chance that their employer and maybe even insurance companies want to have access to this data. With this data, firefighters can be chosen based on their physical fitness and even on biological means. This would create a competitive environment within the firefighting culture. As discussed in the first chapter, the current firefighting culture can be seen as people-orientated and focused management and in lesser degree on results and innovation orientated. It is difficult to say if this development is good or bad, but it is important to understand that this could be the result of use smart technology.

Looking at these consequences, you can argue that there will be a lot of resistance against smart technology within the fire department. But the world around them is changing quickly and is embracing smart technology, if the fire department wants to be able to be effective firefighters in the future as well, they should not stay behind. Knowing these possible consequences, we could move this development in the preferred way.

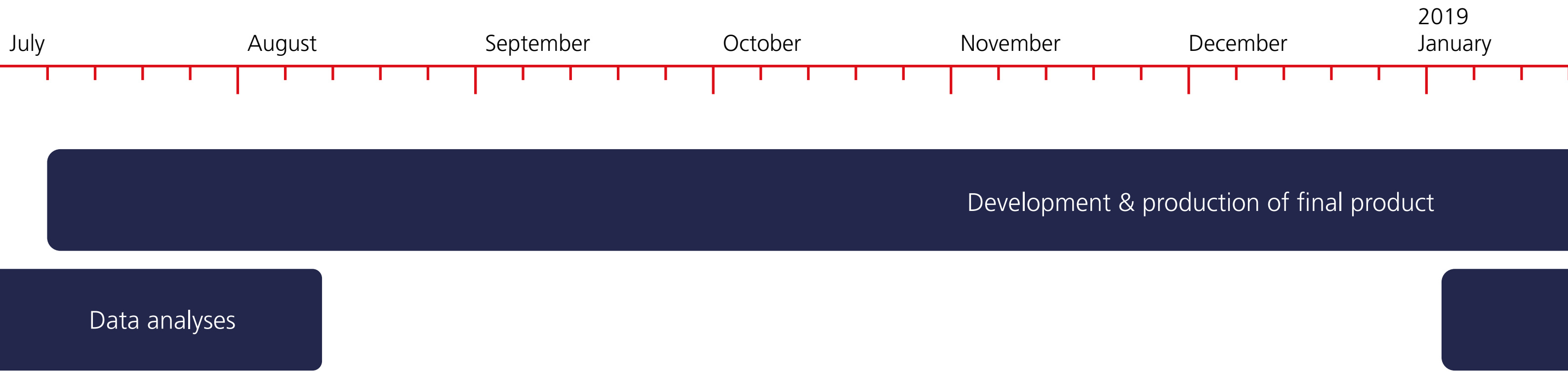
Figure 61. QuantiFire Earpiece render

Next steps



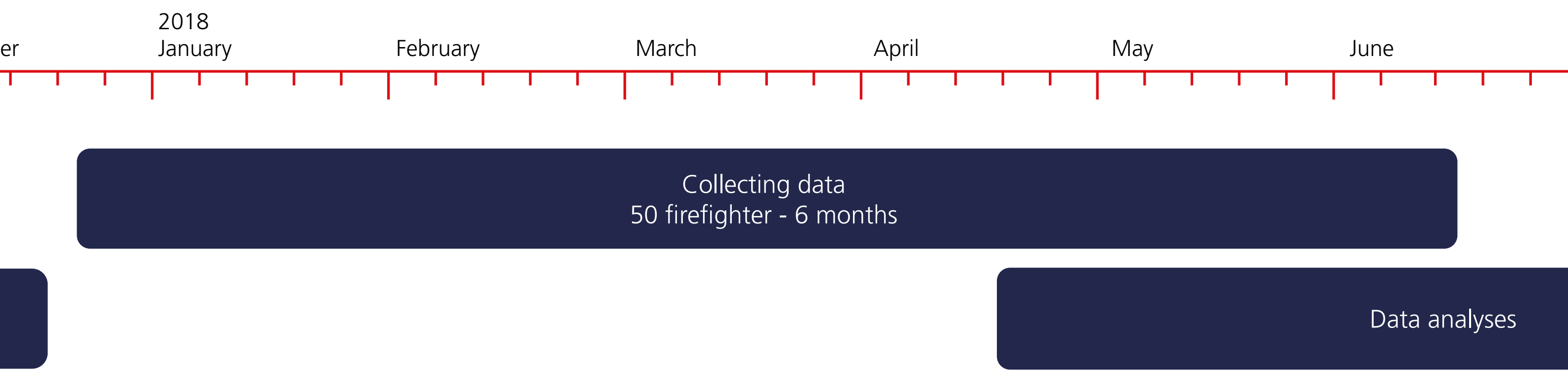
Get in contact with research institutes and suppliers like IFV and Dräger for possible cooperations. Setting up a preliminary test by crating or purchasing devices that can measure biometric data. Perform market research and use the key influencers of the market from chapter two to drive the market. Make people aware of the problems of heat illness.

The devices are used to gather physiological data with a small test group. ±3 firefighters over a period of 2 months. This provides insight whether the project is feasible or not. During and after this test period, 50 working products will be build which can be worn by firefighters over half a year.



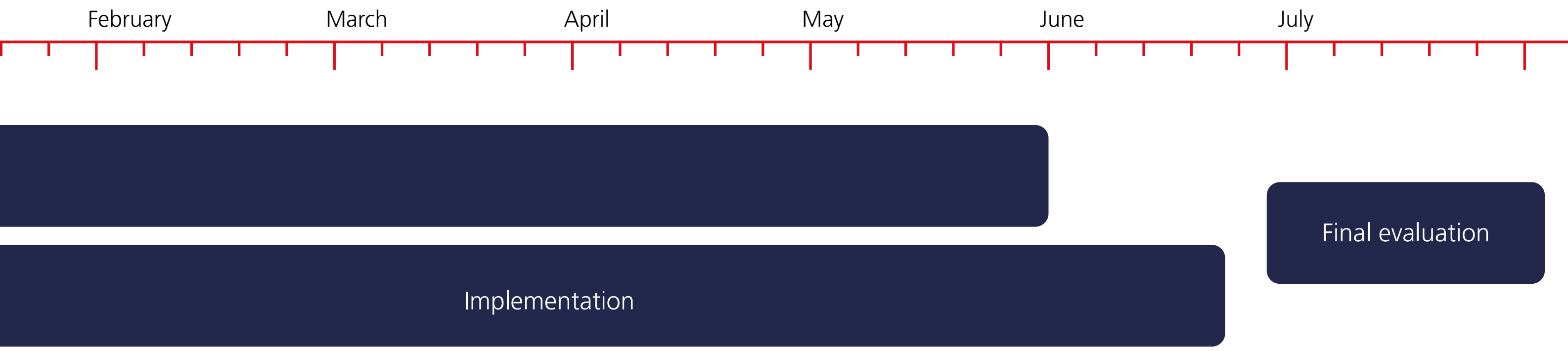
The final product will be developed in collaboration with the supplier. The development includes the design, testing and production of the final product, the smartphone app and the software of the system.

Figure 62. The next steps for future development of the QuantiFire system



A group of 50 firefighters will wear the product over a period of 6 months. In this period enough data will be collected to preform analyses. In 6 months 50 sessions per firefighter can be measured.

The large amount of data will be used for data analytics. Data scientists from Schiphol will try to find patterns in the data that can predict if someone is likely to get a heat stroke. Next to that, crowdsourcing competitions are set up on websites like www.kaggle.com. The result will be a reliable algorithm for the final device.



When the product is ready. All firefighters should get one earpiece per person.

An evaluation of the product will be made after a period of useage of the product.

Self reflection

Before starting my project, it took me a while to find the right assignment. My goal was to find an project that involved new technology such as internet of things, artificial intelligence, etc. I wanted to learn how to implement these technologies in a new design and in prototypes. Beside that I wanted to learn how to fit the design to the business aspects and to create a future vision.

I finally got the opportunity at Schiphol, which met exactly my expectations. My assignment was not set at the beginning, so I could choose my own, which was a hard choice. Making decisions is not my strongest skill. I am happy that I finally ended up with the assignment for the fire department. It was a total new world for me and it felt like a childhood dream to come true (I think every boy wants to become a fireman once).

In the beginning of the project I took some time for orientating. I had a lot of meetings with different people within Schiphol and I visited fire exercises. This helped me to scope the project. Then I spend a lot of time on planning my project, I was not sure which methodology to apply. At Schiphol they where just implement the agile methodology Scrum, which sounded promising. However, I realized later that this it is difficult to implement in a design project, because it requires fast decisions and quick prototyping. Scrum originates for software development and it is much easier to make a digital prototype than a physical one. Therefore I chose not to go for this method. However, I used some elements of it. Because I was in close contact with the users, the firefighters, I could do a lot of testing with them.

I did a creative session with firefighters, I participated in a 24 hour service, I could visit a large exercise with firefighters, ambulance staff and marechaussee, I did a validation test with security cameras during a fire exercise, I did measurements during a large exercise in Wijster and my final concept was tested with firefighters. I learned a lot from these sessions. I learned how to organise them and how to get the result from it that is needed.

Because the project started with a broad assignment, my idea was to approach my projects from two sides. First find out what the needs are of the firefighters, and secondly to search for new technologies and then try to combine these two to get some design directions. Therefore, I plotted all the emerging technologies, gathered from Gartner and a few from other places, on so called technology card. My idea was to use these cards to cluster them according to the needs of the firefighters. Making the cards took a lot of time and the result was not as I was expected. I did learn some things about new technologies. However, only the technologies that I already knew where interesting for the project. This caused me to lose a lot of time in the middle of my project. Besides that, I had a hard time to make the decision on which design direction to continue with. I had the feeling that I didn't had the rig=ht criteria yet to base my decision on.

I realized I had to take another approach. I start reading up in the Design Driven Innovation method and made a few appointments with different people from outside Schiphol who where related to firefighting. I tried to find people who where related to the business side of firefighting, research side and some people that worked on innovation projects for firefighters. These meetings, finally helped me a lot in making the final decision. It enabled me to take a more helicopter view on the project and to look at what the future of firefighting will look like. It is a pity that I didn't had these meetings at the beginning of the project. It would have saved me a lot of time.

After I made the decision to continue with the health direction, and to focus on heat illness, I realized that I could spend another whole graduation project on developing a product that would solve the problems with heat illness. I had to learn everything about heat illness, I had to find out how to recognise it and design a product for it. After a stressful time, I managed to do most of it. However, the final design was not elaborated as far as I wanted at the beginning of the project. I focused a lot of time on the physical aspect of the design, but I could have spend more time on validating the business and service aspects of the concept. After submitting this report I will present my project at the fire department, I hope this will help me to validate that.

During the project I learned a lot about implementing smart technology, how to make it fit to the business and to make a future vision, which I wanted in the beginning. Maybe the most important thing that I learned is how to perform and organise a design project on my own. It was sometimes a stressful project because I set my goals very high and making decisions was hard for me. Besides that, I learned what it is to work at a large Dutch corporate, which is different from what I was used to from my internships (furniture company Lensvelt and toymaker LEGO in Denmark). Schiphol is more business focused and I realise that it can takes some time to get things done.

I underestimated writing the report. It took me much more time than expected. I found it difficult to express myself in English and to make a clear and logical story. At the end, I think I managed to write a clear report and Im happy with the overall results of the project.

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