Smart safety shoes

The next step in preventing occupational incidents

MASTER THESIS

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Here is an overview of everyone who has shown great support in my project through time, advice, emotional support or creativity. I would like to take this page to show my gratitude towards each one.

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I would like to thank my family for the support I received, the network I could make use of for experts and the feedback on work when necessary

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I would like the thank my supervisory team: Wilfred, Jeroen and Viki. They made me go the extra mile and provided excellent coaching to guide me when necessary.

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A special thanks to Alessia Braams, who made sure the writing of this thesis did not devour me in the process.

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Lastly, I would like to thank my friends for helping me out with brainstorm session.

List of abbreviations

AI - Artifical Intelligence
ASE - Attitude, Social influence and self Efficacy
BBS - Behaviour-Based Safety
CPU - Central Processing Unit
DALY - Disability-Adjusted Life Year(s)
DAWY - Daily-Adjusted Work Year(s)
GDPR - General Data Protection Regulation
GRP - GreenRoad Project
H&S - Health and Safety
IMU - Inertial Measurement Unit
IoT - Internet of Things
IPD - Industrial Product Design
LED - Light Emitting Diode
ML - Machine Learning
MSD - MusculoSkeletal Disorder
NN - Neural Network
PC - Personal Computer
PCB - Printed Circuit Board
PPD - Plantar Pressure Distribution
PPDP - Plantar Pressure Distribution Profiles
PPE - Personal Protective Equipment
QALY - Quality-Adjusted Life Year(s)
RIVM - Rijksinstituut voor Volksgezondheid en Milieu
RFID - Radio Frequency Identification

Abstract

The construction and logistics sectors in the Netherlands are rapidly increasing in size, but unfortunately are also part of the most hazardous industries. One part of safety which needs to be addressed is manual handling related incidents. The moving of objects around a worksite through utilization of an employee's body increases the exposure of the employees to hazards, especially if done incorrectly, and will increase costs for both employee and employer. This thesis explores the possibility of transforming the passive and reactive role of safety shoes into safety shoes that are capable of proactive (manual handling related) incident prevention, through utilization of smart technology.

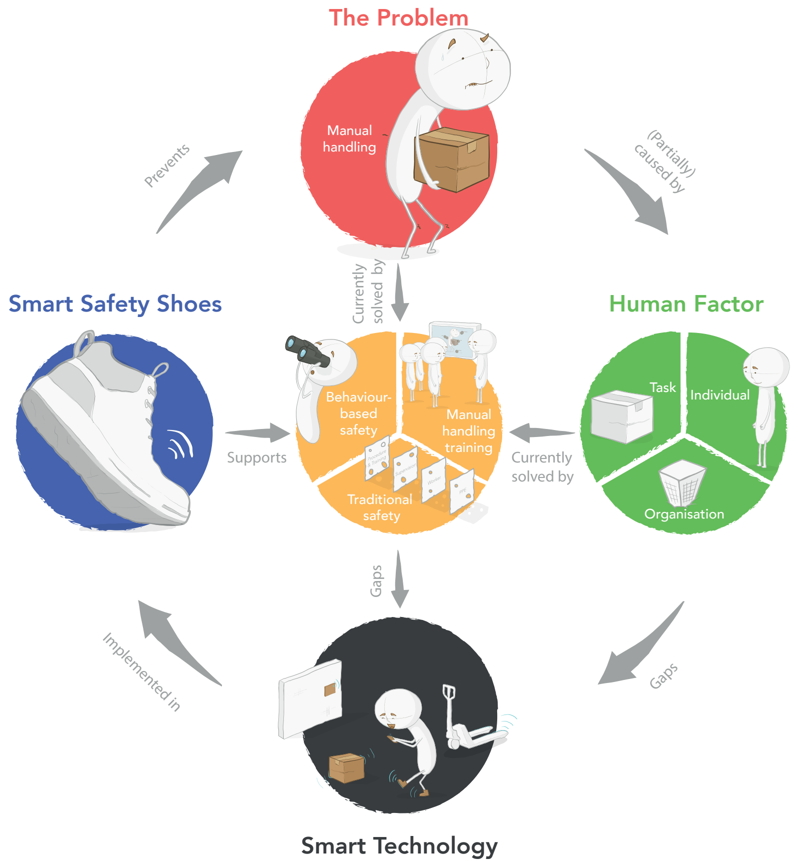
To gain insight into the problem, its context and the possibilities for the implementation of smart technology, an extensive literature review was conducted. In addition, practical field knowledge was gained through multiple series of semi-structured interviews and analysis of relevant cases.

Research results show that the human factor plays a major role in the causation of occupational incidents and can be divided into three categories: the individual, the task and the organisation. As this human factor is either the leading cause or part of the cause for around 80% of all incidents, it is vital for incident prevention.

Furthermore, current methods for detection and prevention (e.g. manual handling training and safety programs) have serious shortcomings which make them less effective tools for the reduction or elimination of manual handling related incidents. In addition to this, studies indicate the opportunity for (smart) technology to aid in overcoming these shortcomings.

The above mentioned insights served as input for the synthesis of a concept design (smart safety shoes), which uses sensors and data analysis tools (e.g. machine learning) to identify and detect leading and lagging indicators for manual handling related incidents and subsequently is able to effectively communicate those insights to different parties: employees, employers, supervisors and training providers. The smart safety shoes can, in this manner, support current detection and prevention methods in their shortcomings. The before mentioned parties deploy the insights through a hybrid system: reactive incident prevention (improve the individual) and proactive prevention (improve task design and organization), which both, increase incident prevention. The concept design is accompanied by a roadmap outlining the general steps for the development of the concept.

To conclude, smart safety shoes are the next step towards occupational incident prevention and potentially the first step towards smart, ubiquitous, occupational safety. However, further research is needed for the development of the smart safety shoes and the exploration of further possibilities. In addition to this, the principles behind the smart safety shoes could serve as a basis for further design research, to address other occupational safety issues and other industries.



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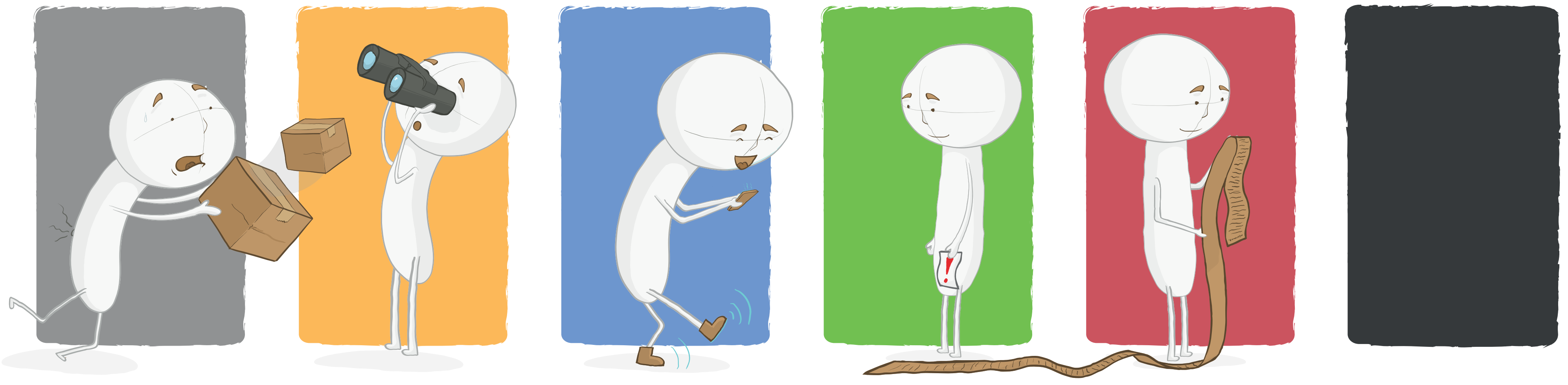


Introduction

The following section will explain the reason for the existence of this project, what the problem is and why it is important to address this problem. The section will also elaborate on Allshoes, the involved company, and why this company is of importance.

Next to this, the following section will discuss my design methodology and approach for this project and what the main research question and purpose of this thesis are.

Lastly the introduction will provide an overview of the chapters of the thesis and briefly mention their contents.

The purpose of this section of my thesis is to prepare the reader for the rest of the thesis, explain the setup and provide context to help the reader understand and immerse themselves in the project in a quick manner.

1

Project

The first subchapter of the introduction covers the project setup. It will go into the origin of this thesis (illustrate its importance), the process and methodology used throughout this project and the company for which the project was set up. This subchapter will end with the assignment description (main research question) and the reader's guide.

1.1

Introduction

This section will briefly explain the insights that lead to the starting point of this thesis. It will quickly go over the general scope of the project and the reasons why this project was set up.

“The Netherlands excels at logistics, construction and transport and these industries are growing fast! A huge number of people work in these sectors and working in warehouses, on construction sites and/or with heavy equipment involves risks. Since safety is crucial, we are investigating ways to minimize the risk and consequences of injury. Safety shoes are required in many workplaces and 1.5 million pairs of safety shoes are sold in the Netherlands each year, with Allshoes Benelux BV as market leader”
(Arts, 2020)

In the Netherlands, the number of occupational accidents has been increasing each year, leading up to a total of 4250 incidents in 2017. On the contrary, the number of fatal accidents in 2017 compared to 2016 has decreased from 70 to 50 (Pieters, 2018). From this can be concluded that although we become better at reducing an accident its impact, we are not getting better at preventing them, or perhaps even getting progressively worse.

For this project I will target the construction and warehousing sectors. These two groups are the biggest client groups for Allshoes (Arts, 2020) and they are both part of the most hazardous industries (CBS, 2014; Wu, Yang, Li, Chew, 2013). Next to the high number of injuries in these sectors, the construction sector is also seeing early retirement, occupationally caused back disorders and high physically demanding work (Choi, Hwang, Lee, 2017). Therefore, it is no surprise that in construction and warehousing about one in three employees mentioned they regularly perform heavy physical labour (Hooftman et al., 2019).

On average in the Netherlands, the costs associated with the absence of workers due to physical work that is too demanding comes in at 4581 Euros, per person per year. There are about 164,000 employees each year who lose workdays over complaints due to physically heavy work (TNO, 2014).

Because of this market size and level of hazards and costs involved, the positive impact of addressing these occupational hazard seems promising, adding to the practical relevance of this project.

In this thesis, I will focus on the safety and risks concerning manual handling. Manual handling means utilizing the worker’s body for transporting or supporting of any kind of materials on the worksite. In construction, 64% of all workers are subjected to manual handling with heavy loads, for warehousing this percentage is 42%.

The most associated injuries related to manual handling are back disorders. In fact, in these sectors it is common for new employees to get their first sightings of back aches within their first year of employment (OSHA, 2006). Labour intensive work in general is one of the main reasons for back problems in the Netherlands (Volksgezonheidenzorg, 2019). The impact of back problems on lifespan in the Netherlands is the number eight on the Disability-Adjusted Life Years (DALY) list, number four for the ages between 15-65 (Volksgezondheidenzorg, 2018[2]) and amongst the top ten globally (Duthey, 2013). Back problems can cause discomfort and physical limitations (Hartvigsen et al., 2018; Hoy et al., 2014).

An important factor in the causation of incidents is the human factor. This applies to incidents in general (Hofstra, Petkova, Dullaert, Reniers, Leeuw, 2018) as a major contributor and to even as the main contributor in construction (Juhari, 2019). This human factor is characterized by attitude, dangerous behaviour, competency and the psychological and physical human (Juhari, 2019). Other studies describe this human factor as not obeying safety protocol (Harvey, Waterson, & Dainty, 2018) or workers their (unsafe) actions (Winge, Albrechtsen, & Mostue, 2019). To add to that, behaviour-based safety (BBS) has been shown to be an effective tool for increasing workplace safety (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015), which emphasizes the role of the human factor in incidents.

A study suggests that next to people and procedures, technology is the third (and final) important factor for a safe workplace. According to the study, technology can help minimize risk of and exposure to hazards (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015). Smart technologies are able to detect and prevent incidents before they happen, shift group risk assessment to personal risk assessment and change periodic risk assessment to a continuous real-time risk assessment (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016).

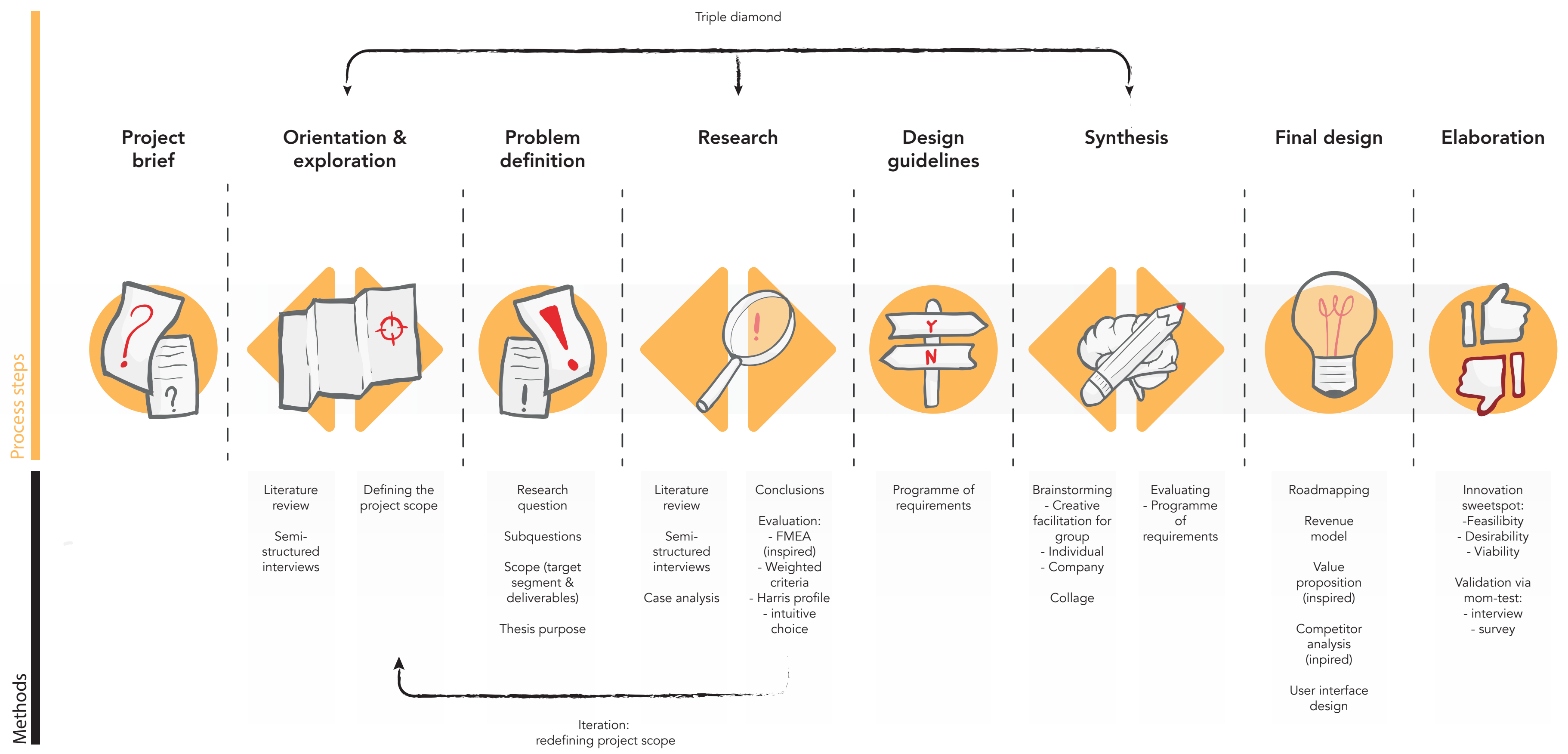
An excellent reason for exploring the possibilities to proactively prevent incidents with personal protective equipment (PPE), is that these are always obligated in hazardous environments, for everyone. The reason for choosing to utilize the shoe over other PPE is that out of all the PPE, the shoe is the one piece that will always be present in hazardous situations. Helmets and gloves are taken off much more easily and not obligated in every situation. However the shoe is obligatory once you enter the worksite. A survey by Kimberley-Clark Professional shows that noise protection, respiratory masks and protective clothes belonged to the highest PPE non-compliance (16-18%). Protective gloves came in at 14% and helmets at 4%, meaning safety shoes have a compliance rate higher than 96% (ISHN, 2011).

All in all this presents a promising opportunity for smart incident prevention through smart personal protective equipment (PPE). More specifically, through smart safety shoes.

Company

Design methodology

The process which was used in this thesis is visualised below. Throughout the project, different design methods were implemented, which are listed in the visual as well. Although the project contained multiple iterations, only one is significant enough to mention: redefining the project scope and with that the research question.



Assignment

Following from this conclusion, is the main research question of this thesis:

How can smart technology in safety shoes, in warehousing and construction, contribute to proactive incident prevention in manual handling?

In order to be able to answer the main question, it needs to be divided into sub-questions:

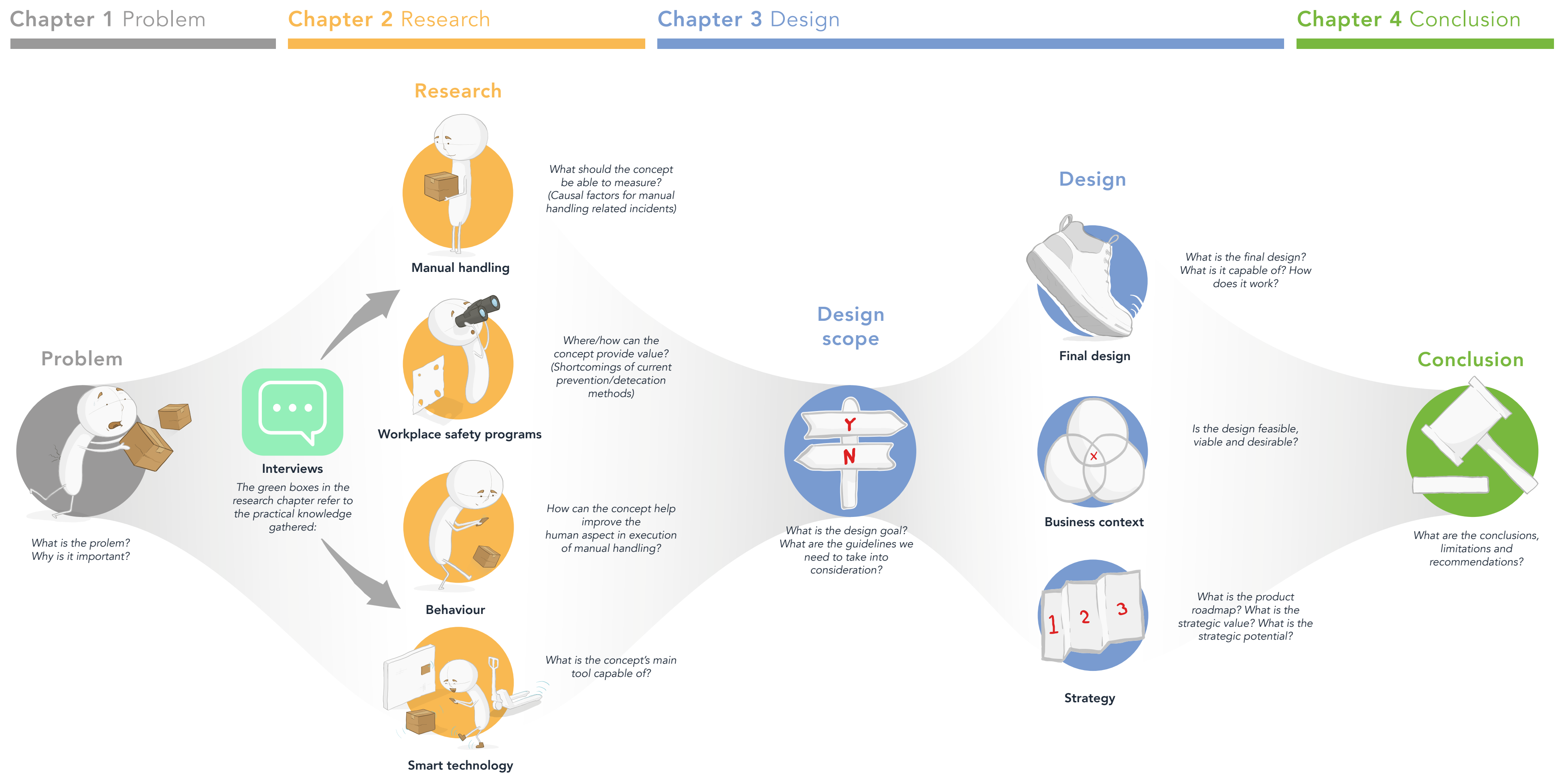
- *What is safe manual handling?*
- *How does safety in these sectors generally work?*
- *What is the influence of behaviour on (un)safe manual handling?*
- *What causes unsafe behaviour?*
  - *What causes unsafe manual handling behaviour?*
  - *How can (unsafe) behaviour be (positively) influenced?*
- *What is smart technology?*
  - *What are the possibilities of smart technologies (in shoes)?*

The purpose of this thesis is to explore the possibilities of smart safety shoes in terms of viability, feasibility and desirability. This thesis poses as a starting point for the design of prototypes.

This project focuses on manual handling related problems in construction and warehousing sectors. Also I will scope down the project by not aiming for a working prototype but a concept, which is feasible (within context), viable (strengthening Allshoes' (future) market position even more) and desirable (by all involved stakeholders).

Reader's guide

The rest of the first chapter of this thesis, chapter 1, will dive deeper into the problem. It will cover the prevalence and incidence of the problem at hand: manual handling. In chapter two, the insights of four different bodies of research will be covered to answer the main research question of this thesis. The different bodies are manual handling, workplace safety, human behaviour and smart technology. The green boxes in the second chapter refer to practical (field) knowledge that has been gathered. The references in these boxes refer to the different individuals that I have spoken to. In the references chapter (at the end of the report), a list is presented with who these individuals are. The third chapter, design, shows what considerations were made for the final design and present the final design itself, including the viability, feasibility and desirability aspects of the final design. Chapter three will close off with covering the strategy that corresponds to the implementation of the final design. Lastly, chapter four, will wrap up the main part of the thesis with conclusions, limitations, recommendations and a personal reflection. After the conclusion is the references chapter and the appendices.



Problem

The following subchapter will dive deeper into the problem that will be covered in this thesis. It will focus on the severity, prevalence and incidence of the problem. The main purpose of this subchapter is to illustrate the importance of dealing with this problem and the potential value that could be gained from doing so.

1.2

The Problem

The next section of this thesis will go into the impact of incorrect manual handling and the importance of focusing on manual handling and the problems that come with it.

Severity of the problem

When incorrect manual handling technique is used or employees are lifting too heavy or frequent, this can cause physical issues like cuts, bruises, fractures neck and limb disorders. The most important physical issue, however, is back disorders (OSHA, 2006; Hogan, Greiner, O'sullivan, 2014). A literature review showed that 16 (out of 19) studies found a positive relation between manual handling and back disorders (Hogan, Greiner, O'sullivan, 2014). In fact, labour intensive work is one of the main reasons for back problems in the Netherlands (Volksgezonheidenzorg, 2019). Once back problems occur, there is a high probability it will reoccur or even become chronic (Hartvigsen et al., 2018).

Costs of injuries can be divided into three categories: direct costs, indirect costs (Hogan, Greiner, O'sullivan, 2014) and Health&Safety (H&S) program costs. Direct costs are costs that are directly related to the incident, for example worker compensation. Indirect costs are costs that are indirectly related to the accident (Haupt & Pillay, 2016), for example productivity loss, higher insurance costs (Hogan, Greiner, O'sullivan, 2014), reputation loss and replacement personnel. The last type of costs is H&S costs, which are measures taken to prevent incidents, for example inspection and PPE. Another important cost that come with the direct costs is quality of life, which is significantly bigger than the workplace disruption costs (Haupt & Pillay, 2016).

The impact of back problems on lifespan in the Netherlands is the number eight on the Disability-Adjusted Life Years (DALY) list, number four for the ages between 15-65 (Volksgezondheidenzorg, 2018[2]) and amongst the top ten globally (Duthey, 2013). The DALY is a metric used to indicate how many years (in good health) are lost due to a disease or condition. In 2015, health problems due to physical labour accounted for 15.8% of the total amount of work related disease burdens in the Netherlands, coming in at 35.000 DALYs in a year (Volksgezondheidenzorg, 2018[1]). Back problems are even the biggest cause of absenteeism in the Netherlands(Arboportaal, 2019) and costs the Netherlands about 900 million in treatment a year (not including other financial costs, like worker compensation or indirect costs) (Volksgezondheidenzorg, 2018[3]).

As mentioned earlier another factor to take into account is the impact on quality of life (Hogan, Greiner, O'sullivan, 2014). A metric used for this is Quality-Adjusted Life Years (QALY), which is the loss of years in perfect health. A study shows that QALY loss due to chronic back pain is 64% (Geurts, Willems, Kallewaard, Kleef, Dirksen, 2018). This makes for a substantial reduction in the well-being of employees, which according to a study is related to employee performance (higher productivity, lower absenteeism and higher retention) (Baptiste, 2008). In addition to this, other studies also found relations between occupational health & safety and employee satisfaction, which subsequently has a relation with employee performance (Ahmas, Sattar, Nawaz, 2017; Bayram, Ünğan, Ardıç, 2016). Quality of life loss due to back problems can include discomfort and physical limitations: Psychological distress, mobility difficulties (like dressing, sitting, standing, walking and lifting) (Hartvigsen et al., 2018), constant back pain, poor quality of sleep and loss of life enjoyment (Hoy et al., 2014).

The RIVM (Rijksinstituut voor Volksgezondheid en Milieu) performed a study into a new metric for incident costs: Disability-Adjusted Working Years (DAWY), which refers to the loss of years employees are able to work for. This metric includes absenteeism, work disability and productivity loss. In Holland the DAWY for back complaints, on annual basis, is calculated to be 16.000 (RIVM, 2010).

Per person per year, on average in the Netherlands, the costs associated with the absence of workers due to physical work that is too demanding comes in at 4581 Euros. Their daily salary is around 183 Euros on average, which will have to be covered by the company in case of a lost workday (TNO, 2014).

"I have seen many people loose total confidence in their own body and mind because of back pain. It makes a huge, HUGE, impact on life quality. Those with back pain are barely able to do anything and they have to endure the pain 24/7 until it is over."
- Appels, 2020

As illustrated in the quote above, the interviews support the literature, on how big of an impact back disorders have on a person's life. Next to that, the well-being of employees was also mentioned in an interview, with an H&S manager, as the greatest incident cost (Monis, 2020). Another loss, that can be directly correlated to the well-being, is retention. As soon as overall well-being goes down, so will the retention rate. Along with this will develop a loss of reputation, decreasing the likelihood of new employees wanting to work for you, too (Metselaar, 2020).

According to Metselaar, an incident can easily cost up to 400 Euros per day (of course depending on the severity). Financial costs for companies, once back problems cause absenteeism, are made up of several components: Absent worker will cost 1.4 times the normal salary, replacement will cost 1.7 times the normal salary, a company doctor can quickly cost 70 Euros an hour, treatment for the patient will have to be covered and there will be a loss of productivity (resulting in financial loss, too). Productivity loss due to back pain was estimated to be at least 3% of the total work capacity (Appels, 2020). Time and productivity loss were mentioned by another interviewee too, as the second biggest costs of incidents (Monis, 2020).

Occurrence of the problem

Handling goods and materials are frequent and important activities in construction and warehousing. In 2018, one in five Dutch people mentioned they regularly perform occupational related physical intensive labour (lifting, pushing, pulling, heavy equipment) (Hooftman et al., 2019). In construction and warehousing about one in three employees mentioned they regularly perform heavy physical labour and another 20% said to do so occasionally (Hooftman et al., 2019). This means that half of the workers in these sectors is exposed to an increased risk of developing a back disorder.

There are 145.800 cases in the Netherlands of back problems shortening people their lifespan each year (Volksgezondheidenzorg, 2018[2]). Also, there are about 164,000 employees each year who lose workdays over complaints due to physically heavy work (TNO, 2014).

An incident report by Bunzl Continental shows that a considerable portion of their incidents are related to manual handling. From the 500 total incidents in about two years, the most common incident type is incorrect material handling (66 incidents) (Bunzl, 2020).

Interviews, too, show that incorrect manual handling has a high frequency. In fact, it is even mentioned as the most frequent type of unsafe act (Vandervegt, 2020; Dekker, 2020).

First instances of back problems will usually only cause a one day absenteeism. However, there is a high probability back problems will reoccur. The frequent recurrence of back problems for the same employee will slowly build up to more significant musculoskeletal disorders, like hernias. Incidents like hernias commonly result in a nine month absenteeism (appels, 2020).

All in all, Incorrect manual handling has a high occurrence, high impact, low detection- and prevention rate and solving these issues with technology in the shoes makes sense, as these have a high compliance rate.

Research

This chapter will cover what came forth out of my research for this project. It will only present the insights which are within my scope and of importance to the main research question. The subjects that will be covered are: manual handling, workplace safety, behaviour and smart technology.

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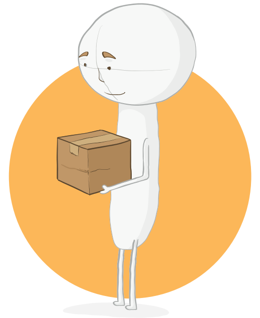
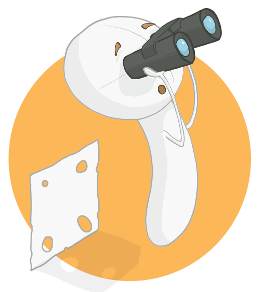


1 Manual handling

This subchapter will discuss what manual handling is and what causes incorrect manual handling. This is important to know as it allows us to objectively assess manual handling, know how to improve incorrect manual handling and eliminate causes.



2 Workplace safety programs

This subchapter will discuss how current workplace safety programs work and what their weaknesses are. This is important to know as it allows us to fit the final design in the context successfully and help reduce shortcomings in the current safety programs.

3 Behaviour

This subchapter will discuss how behaviour works and how it can be influenced. This is important as it allows us to deal with the human factor in the causation of incidents and how to effectively communicate a smart system its data analysis outcome.

4 Smart technology

This subchapter will discuss what smart technology is, how it works and what it is capable of. This is important to know as it allows us to know whether it is capable of improving the workplace safety in the ways mentioned in the other three sections of this chapter.

Manual handling

It is important to know what correct and incorrect manual handling is, as this allows us to assess manual handling behaviour and detect incorrect manual handling. Next to this, it allows us to know specifically what to correct the incorrect manual handling into and prevent manual handling injuries in a reactive manner. Lastly, this subchapter will go into how incorrect manual handling is caused, which provides deeper insights in the source of the problem, allowing for the prevention of incorrect manual handling in a proactive manner.

2.1

Manual handling aspects

The following section will go into what the different aspects of manual handling are. Within these aspects will describe what correct manual handling is, what is considered risky or dangerous and what is simply unacceptable.

Manual handling technique

In order to be able to measure incorrect manual handling technique, information on correct manual handling technique is required. Based on these guidelines, a list of features can be generated that can be measured in order to assess manual handling in an objective manner (appendix A). The guidelines for team manual handling operations are excluded, as these are similar to individual manual handling operations, with different weight recommendations (HSE, 2018; HSE, 2016).

Form

Form concerns body posture during the lifting, carrying, pushing and pulling of loads. Figure 2 visualizes the correct and incorrect body postures for the different activities.

• When handling material in a manual manner, bending and twisting the back is considered harmful and should therefore be avoided. Pivoting the body should be done from the feet, not the hips. To avoid a bent back while picking up items from a lower vertical level, the knees should be bent while the back is straight (Arboportaal, 2019).
• Loads should be carried as close to the body as possible, preferably even underneath you when lifting objects (OSHA, 2006). Heavy loads should be carried between knee and shoulder height (the power zone). Whenever the activity involves pushing or pulling, the load its force should be between elbow and shoulder height (Arboportaal, 2019).

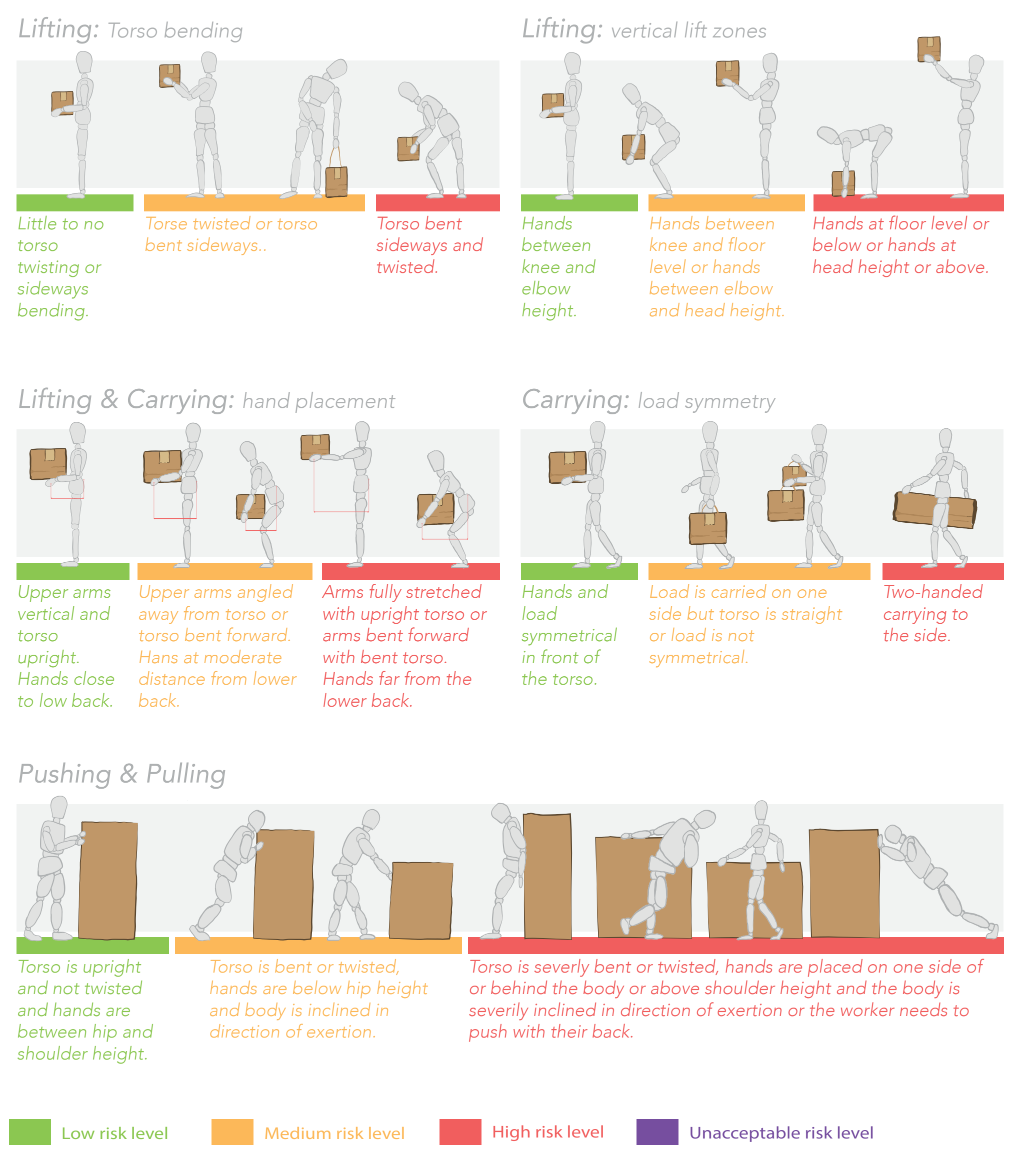


Figure 2: Manual handling technique for lifting, carrying, pulling and pushing, original visuals by HSE

• Pushing (HSE, 2016[1]), lifting and carrying materials should always be done with two hands and lifting always with both feet on the ground (Arboportaal, 2019).
• Reaching for loads should be minimized (HSE, 2016[1]).
• Plantar pressure should be evenly distributed when lifting (HSE, 2016[1]).

Load weight

Another factor in correct manual handling is the weight of the load that is being handled. Figure 2 visualises how heavy a load can be for different activities and tools.

• The load weight at which manual handling risk increases significantly is 23 kilograms. The maximum allowed weight to be handled without equipment is set at 25 kilograms. In case a weight is lifted with two workers, the maximum allowed load weight increases to 50 kilograms (Arboportaal, 2019).
• Maximum recommended weight can be influenced by other factors: e.g. load position (see figure 2) (HSE, 2020).

Duration and frequency

The third factor of correct manual handling is the duration, distance and frequency of a load being handled. Depending on the load weight and the type of manual handling task (pushing, lifting, carrying and pulling), a load can be handled for different distances, frequencies and durations.

• Depending on the task and the amount of weight involved, tasks can and should only be performed for a certain time period. The heavier the weight and the more stress inducing the task and the shorter the advised duration of the task. These task durations can be calculated with a risk factor (Arboportaal, 2019).
• Loads should only be carried up to a distance of 4 meters. Up to 10 meters is allowed, but increases risk significantly. Above 10 meters is unacceptable (OSHA, 2018). For pulling and pushing loads

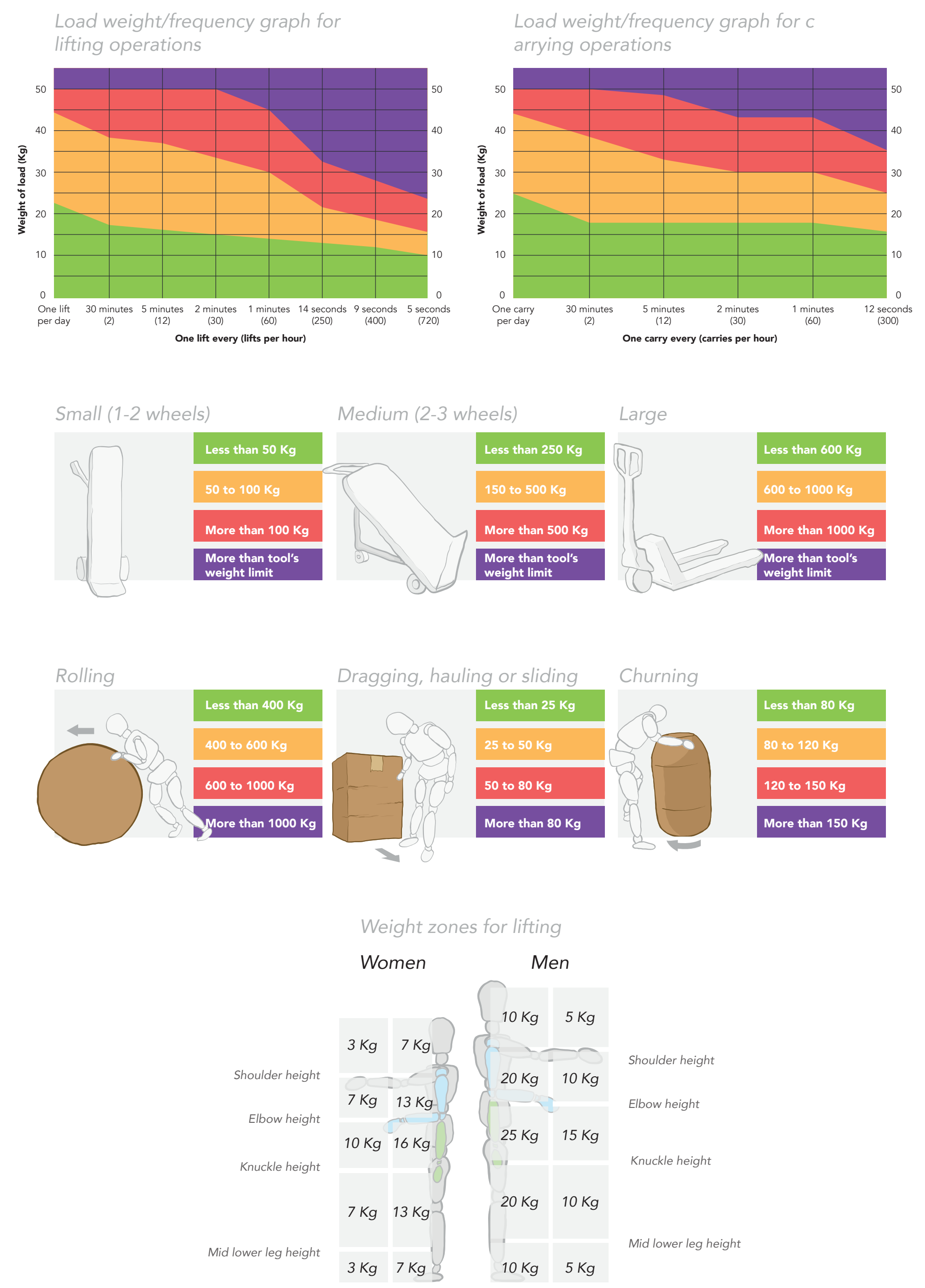


Figure 3: Manual handling load weight limits, original visuals by HSE

these distances are 10 meters, 30 meters and above 30 meters, respectively. For pushing and pulling loads without wheels, these distances are 2 meters, 10 meters and above 10 meters, respectively (OSHA, 2016).
• The frequency of tasks depends on the load weight (see figure 2) (OSHA, 2018).

Acts

Certain acts in manual handling can increase risk. While incorrect form or handling too heavy loads are also unsafe manual handling acts, these will not be included in this category. Figure 3 visualizes the unsafe manual handling acts.

• Employees should never try to catch falling loads, especially heavy or large loads (Bunzl, 2020).
• Whenever possible, equipment should be used to carry materials (HSE, 2020).
• Load size should never cause obstruction of sight. Employees should always be able to look over the load (HSE, 2018).
• Jerking weights increases the risk, therefore loads should always be handled with a controlled movement (HSE [2], 2016).
• Employees should always look up and ahead, when carrying weights. This way they are more aware of their surrounding (HSE [2], 2016).

Environment

The last element in manual handling technique is environment. The physical environment around an employee can increase the risk involved with manual handling.

• Employees should always do a risk assessment and planning of manual handling before starting the task (OHSA, 2006). Environmental factors which should be included in this risk assessment are: postural constraints (lack of space), floor surface (grip, level differences,

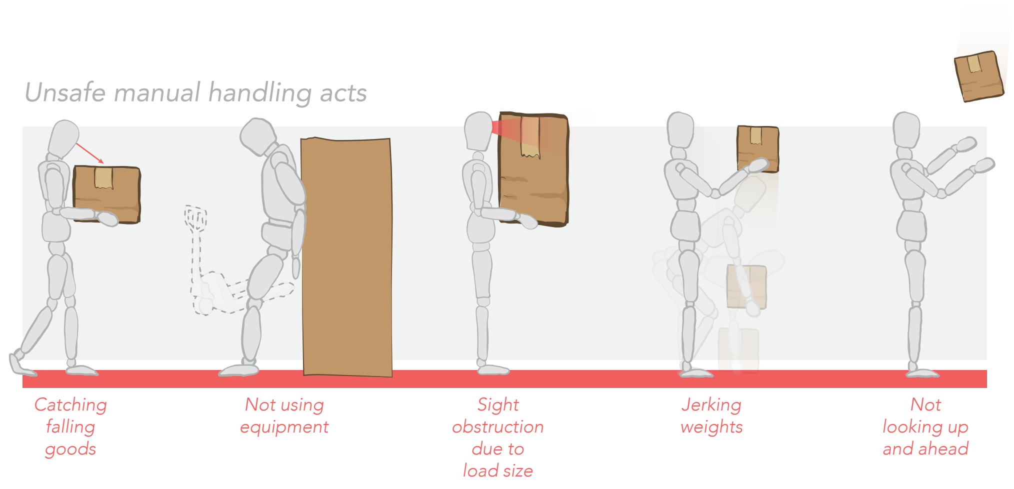


Figure 3: Manual handling unsafe acts

damage and firm), load characteristics (stability, grip quality, size, sharp or hot), obstacles on route, environmental factors (for example light, temperature and humidity) (OSHA, 2018), work patterns (repetitions and pace), equipment and tools (condition of functional parts) (OSHA, 2016).

Conclusion

There are five different aspects to manual handling: form, load weight, duration & frequency, acts and environment. These five aspects describe the quality of a manual handling task. If these aspects are taken into consideration when manual handling is performed, the risks should be minimized. Furthermore, These aspects can be used for as a form of objective manual handling assessment.

Manual handling incident causes

The next section of this thesis will go into why incorrect manual handling could occur. It will go into the different causal factors, both manual handling specific causes (which are directly related to this type of incident) as well as general safety failures (which have a more indirect relation).

General causes

As mentioned in the introduction of this thesis, the human factor plays a major role in the causation of incidents (Winge, Albrechtsen, & Mostue, 2019; Juhari, 2019; Hofstra, Petkova, Dullaert, Reniers, Leeuw, 2018). It is estimated that amongst all occupational incidents, 80% is either fully or partially caused by the human factor. This human factor is divided in three aspects: the work task, the organization and the employee. First of all, the work tasks should have a physical and mental match with the physical and mental capabilities of the employee performing that task. Secondly, the organization, in general, should promote a corporate safety culture, as well as safe practices. Finally, employees have their own way of working, which is made up out of their competences and behaviour. In turn, this will influence their ability to execute the work tasks correctly and properly assess the involved risk (HSE, 2007).

There are two different layers in which these human factors make impact. 1) front-line failures, which are called active failures. These failures cause immediate incidents: e.g. an employee catching falling goods and as a result injuring themselves. 2) Set-up failures, which are called latent failures. These failures do not cause immediate incidents but have a delayed effect (HSE, 2007): e.g. improper ergonomic training, which will later cause an employee to incorrectly lift an object and injure themselves.

As the previous paragraph already illustrates, unsafe acts do not always originate from the employees themselves. This is influenced by a variety of different elements from its surrounding. In a way, the employees are "set up to fail"(HSE, 2007). Examples for this are: performance pressure, the (hazardous) working environment and materials or tools, management (Winge, Albrechtsen, & Mostue, 2019), demanding work schedules, improper supervision, improper training, improper communication and unclear responsibilities (HSE, 2007). However, according to a study, the elements influencing the worker's actions the most is inadequate risk management and improper immediate supervision (Winge, Albrechtsen, & Mostue, 2019).

One of these environmental elements, specifically for construction, is the constant change within construction sites. This change makes the designing of and complying with safety procedures a lot harder. External factors like weather and unanticipated hazards of the site are hard to take into account. Internal factors like material transport and how the construction site is constantly developing (due to the progression of the construction project) constantly change transport and safety procedures (Harvey, Waterson, & Dainty, 2018)

Next to these factors from an employee's surrounding, unsafe behaviour can also be caused by factors from the employees themselves. Examples of these are: health and fatigue (Winge, Albrechtsen, & Mostue, 2019), capabilities, risk perception and risk-taking behaviour (HSE, 2007).

This unsafe behaviour can either be accidental or on purpose. Accidental unsafe acts are called errors. Unsafe acts which are carried out in a deliberate way are called violations. Human errors can either be skill-based or mistake-based. Violations can either be forced or voluntary. Forced decisions happen only rarely and usually happen when following a rule is either extremely difficult or even unsafe. Voluntary violations are usually routinely and are as a result of an employees lack of care or effort (HSE, 2007). These different origins for the human factor, as causal factor for incidents, are visualised in figure 4.

A study from the university of Loughborough presents another part of the human factor: human culture. The study claims that foreign workers pose a threat to the effectiveness of safety procedures (Ayenimo & Chauhan, 2020). Multicultural workforces face more incidents than monocultural workforces and foreign workers are more frequently part of incidents (Starren, 2016). The Loughborough study suggests that foreign workers have a lower engagement in the worksites because of language barriers, cultural differences, lack of inter-racial social interactions and discriminations, which in turn reduces the engagement in safety protocol (Ayenimo & Chauhan, 2020). An undercover study performed by Bergeijk confirms that a large proportion of warehouse workers in large warehouses like bol.com are foreign and acknowledges that language barriers, as a result of this, are a problem within the warehouse (Bergeijk, 2018).

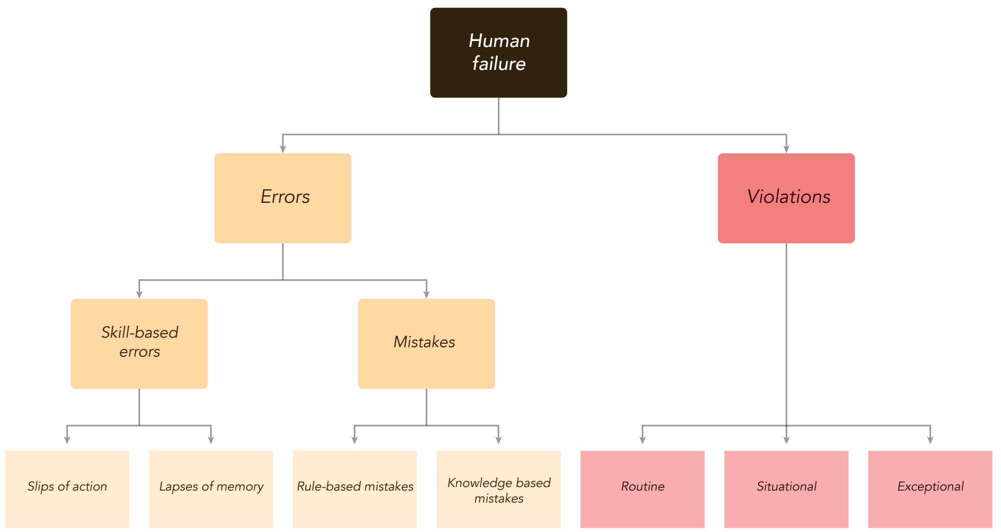


Figure 4: Breakdown of human failure types, original visuals by HSE.

Interviews, too, show that cutting corners and not following procedure are common causes for incidents (Metselaar, 2020; de Vries, 2020). Cutting corners is usually due to a lack of care or effort, time pressure, employees seeing no other opportunities (de Vries, 2020). When procedures are not followed it can cause employees to lift too heavy, in wrong ways and too frequent. (Monis, 2020).

Next to that, in construction, bigger construction companies bring in a lot of contractors. In about one in every 15 projects, most of the employees are hired contractors. These are harder to get a grip on: you do not know how capable they are, what to expect from them and how reliable they are. Contractors might have a different corporate safety culture. All of these factors make it hard(er) to ensure safety procedures and overall safe behaviour (de Vries, 2020). In warehouses, too, outsourced employees come with similar challenges (Monis, 2020).

Difficulties around human cultures and their interference with safety is also acknowledged by both a safety expert and a H&S manager. They both described the safety engagement problems mentioned above. They also mentioned how workplace culture can induce risky behaviour and even prevent behavioural change and technological innovation (for safety). The difficulty with combating an unsafe workplace culture lies in the fact that it is passed onto the newer generations (Monis, 2020); Burink, 2020).

Manual handling specific causes

There are four different areas of factors that influence the risk of failure specifically for manual handling: The task, the environment, the load and the individual . If these factors are in an undesired state, the risk of employees performing incorrect manual handling technique increases, thus increasing the risk for back injuries too (OSHA, 2006).

The task

The risk involved in manual handling increases whenever a task duration or frequency is high (OSHA, 2006; Greiner, 2014). Next to this, if a task involves body postures or movements that are deviating too far from neutral, this is considered hazardous (OSHA, 2006) (commonly referred to as awkward body postures (Greiner, 2014)).

The environment

Factors from the environment that increase the risk of manual handling include the supporting surface that you are standing on while performing the labour, the worksite its physical climate, the worksite its lighting conditions and the available space for performing the labour. Surfaces can increase risk when they lack friction, are angled or uneven or when they are unstable. Undesired physical climate characteristics include high temperature, humidity or air quality. If visibility on the worksite is limited due to bad lighting, this also increases risk. The last environment factor, available space, increases risk by forcing bad body posture due to limited space (OSHA, 2006). Next to these physical risk factors, there are also psychosocial risk factors. These include high demands, low job control or support and absence or lack of rewards (Greiner, 2014).

The load

Factors within the load area are: Load size (OSHA, 2006;Greiner, 2014), weight, balance, location and coupling. Risks increase when load size or weight increases, when a load its centre of gravity is not fixed or offset, if a load its location requires undesired body movement or force and when a load its grip becomes more tedious (OSHA, 2006).

The individual

The individual performing the manual handling is also part of the risk factors. Age, experience, knowledge, physical characteristics (measurements and capabilities), Attitude (willingness to comply with procedures, like PPE), lifestyle and whether the individual has had previous episodes of back injuries (OSHA, 2006).

It is important to note that there is an interplay between these different factors: e.g. if a load weight increases, the duration of a task should decrease. Therefore, all four areas of factors should be looked at as a whole when setting up the required manual handling work. Next to this the study suggests that a person's ability to properly assess risk involved due to the different undesired state of factors, influences the probability of a manual handling incident (Arboportaal, 2019).

The risk inducing factors like prolonged, highly repetitive or fast paced manual handling tasks was also mentioned in interviews (Monis, 2020). Monis also mentions the role of health and fatigue in incident causes. There was, however, no direct causal relation mentioned between health & fatigue and manual handling incidents (Monis, 2020). Environmental factors like rugged or uneven roads and loose parts or rocks on the floor definitely do have a direct causal relation with manual handling incidents (Burink, 2020).

Interviews with warehouse employees showed some other interesting insights. Smaller incidents were not being recognized as incidents, but as part of the job. The same type of attitude applied for near-misses; potential risk is not recognized or acknowledged. Next to this, some workers are not aware of their unsafe acts. These workers thought they acted safely in the warehouse, but colleagues mentioned otherwise. Lastly, some unsafe acts were knowingly ignored due to comfort and productivity reasons (Warehouse workers interview, 2020).

Conclusion

An important cause of incidents (and thus also for manual handling) is the human factor. This human factor consists of three different aspects: The work task, the organisation and the individual. Together they are (partly) responsible for 80% of all incidents. Therefore, this it is a vital element of incident prevention.

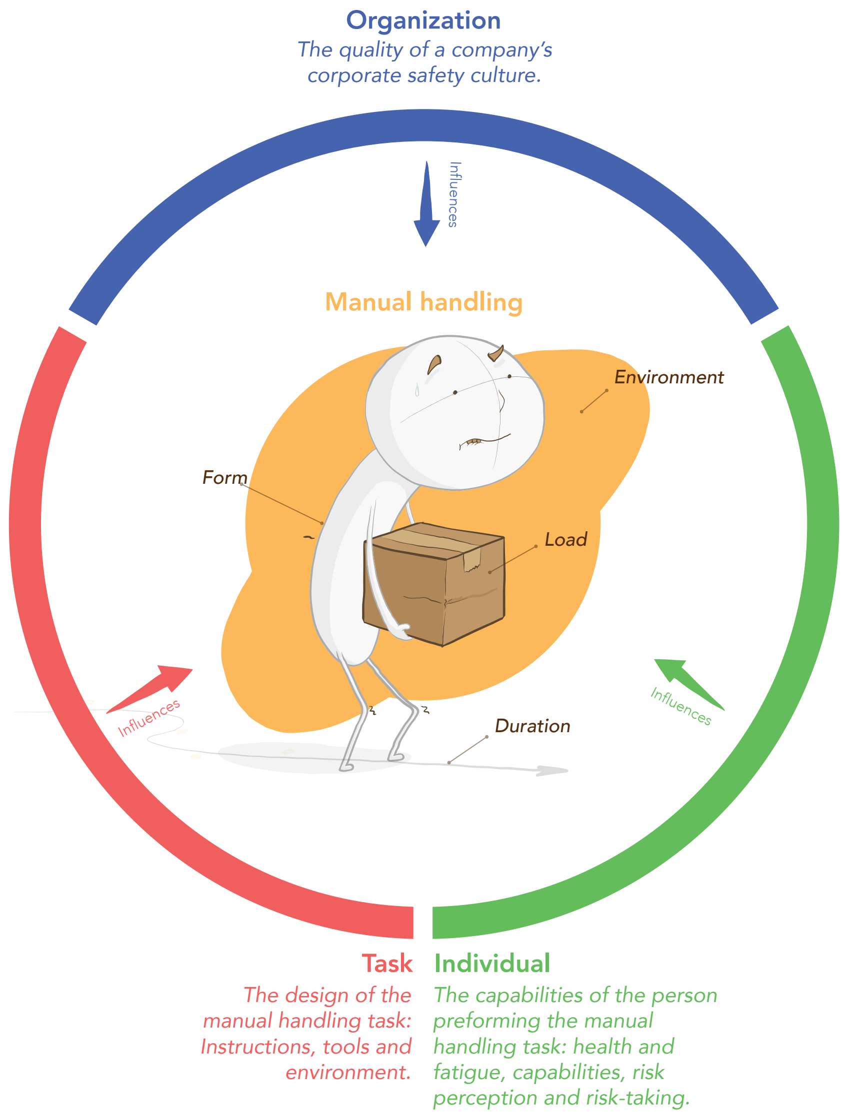
Furthermore, there are two types of human failures in safety, which are active and latent failures. Active failures lead to immediate incidents, latent failures have a delayed effect as they lead to active failures. This makes it important to focus on both for incident prevention.

Conclusion

Correct manual handling considers the following elements: form, load, duration and environment. Whether these elements are of proper quality is influenced by three factors: the organization, the manual handling task and the individual. These three factors are also referred to as the human factor, which (partly) causes about 80% of all incidents. Furthermore, these factors can be utilized for objective assessment of manual handling.

Within these factors, there are two different kinds of failures that cause incorrect manual handling: latent and active failures. Active failures lead to immediate improper manual handling, whereas latent failures create opportunities for improper manual handling and are delayed. These latent failures create a situation in which employees are "set up to fail". The biggest influences for incorrect manual handling are lacking supervision (latent) and lacking risk assessment (latent and active).

Concluding from the paragraphs above, it is important to not only look at an individuals behaviour, but also the manual handling task and the organization. Because of this, it is important to see how currently safety works in construction and warehouse organizations, as well as human behaviour mechanisms.



Workplace safety

Knowing how to improve the current workplace safety, requires knowing how the current safety system functions within warehouses and construction sites. It also requires knowledge on what is being done to prevent or detect these risks and incidents as well as knowing what the gaps and opportunities are. This subchapter will go cover these different topics.

2.2

Generic safety programs

The next section of this thesis will go into how companies are currently dealing with safety issues. In what ways do they (attempt to) prevent and detect incidents (before they happen).

Traditional safety program

Safety is built up in layers. A common safety program starts with procedures (a way of working), followed up by supervision (enforcement of that way of working), followed by the employee (capability of following that way of working) and the last element in this safety chain is PPE (reducing the impact if that way of working fails) (HSE, 2015). However, according to the Swiss cheese model, every layer in this safety chain has its flaws. Because of this, the possibility exists that all the flaws in each of the different layers align, allowing an accident to happen. (Canfora & Ottmann, 2018). Figure 5 visualizes the Swiss cheese model to illustrate the failure chain leading up to incidents. In order to improve safety, it is believed to either decrease the likelihood of hazards or decrease the system its vulnarabilities to them (Reason, 2000).

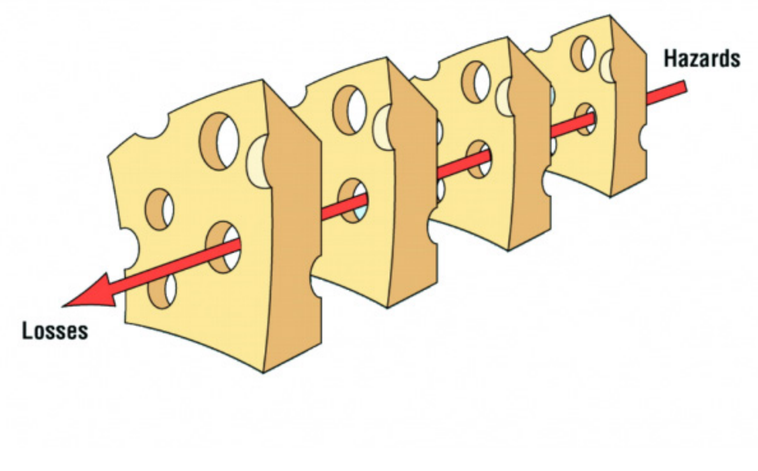


Figure 5: The swiss cheese model, abstract visualisation of safety layers (Larouzee, Le coze, 2020)

There is however one major concern with the first layer in these safety programs; the procedures and trainings are based on lagging indicators, while leading indicators prove more effective (Cary Usrey, 2016). A clear definition, by Cary Usrey, of leading and lagging indicators is presented below:

"Safety leading indicators are proactive measures that measure prevention efforts and can be observed and recorded prior to an injury. As opposed, safety lagging indicators are reactive measures that track only negative outcomes, such as an injury, once it has already occurred."
(Cary Usrey, 2016)

There are two main reasons for the leading indicators to have a better performance in preventing incidents. 1) They are the source of an accident; they are the indicators leading up to the accident. Once identified, they can then be measured and acted upon, perhaps even in real-time. 2) Leading indicators happen significantly more often than lagging indicators (Cary Usrey, 2016). The accident pyramid describes this perfectly; for every accident that happens there are an estimated 300,000 at-risk-behaviours performed (Canfora & Ottmann, 2018). This leads us to believe that these unsafe acts need to addressed to prevent (more) incidents.

Behaviour-based safety

An alternative to the traditional safety program was developed, focusing on behaviour. This protocol is called behaviour based safety (BBS). A BBS program is a program which utilizes behaviours of employees as the basis of safety procedures.

The goal of BBS is to identify and remove any impediments for safe behaviour and implement systems for the encouragement of safe behaviour. Trained observers continuously look for unsafe acts or situations as a source for incidents, and prioritize these for further safety improvements. The underlying principle which differentiates this program from more traditional programs, is that it reassigns safety responsibilities from a company's management to all of those who are present in the company (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015).

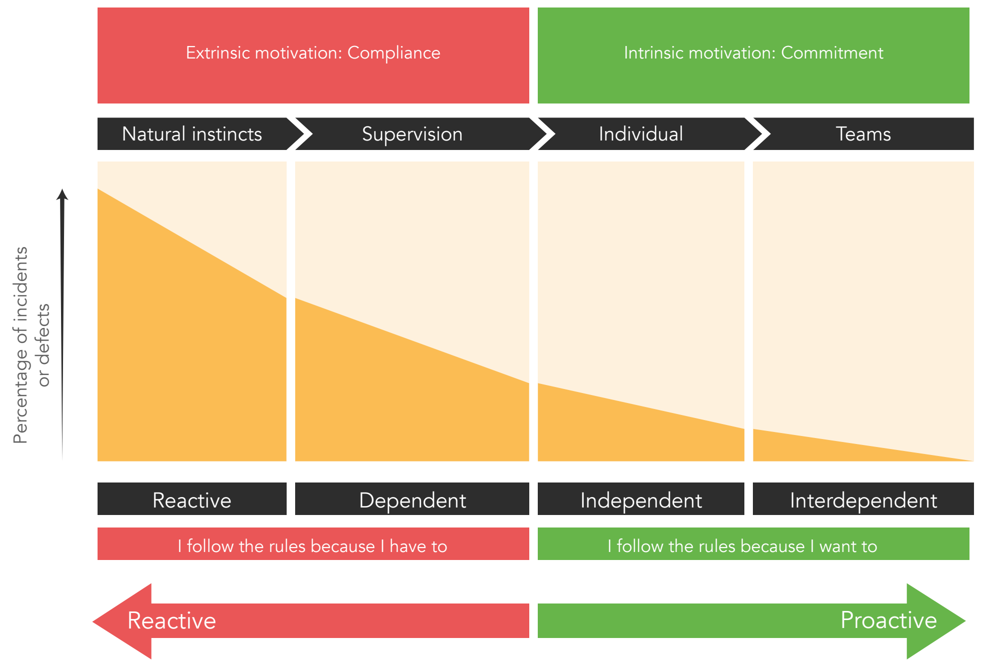


Figure 6: Dupont Bradley curve

The program takes employees their perception of incidents and their workplace as instruments for improving safety. Main techniques in this program include training, behaviour-based incentives, objectives and most importantly peer-to-peer observation and feedback. By teaching employees how to analyse their own and others their behaviour and identifying what is causing hazardous behaviour, employees become more proactive in safety (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015).

A model which describes the process behind BBS is the Dupont Bradley curve (see figure 6). This curve shows the four different attitudinal stages of employees throughout a BBS program. It can help to assess at which stage a company is, which helps with the successful implementation of the program; making a too big of a leap in attitudinal change will result in failure. It shows that in order to get the best result, intrinsic motivation is needed from all employees to have a safe worksite. For this to happen an interdependency is needed, which means that employees should not only focus on their own safety compliance but even support each other to comply with safe practices (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015).

BBS programs have proven an efficient tool for improving workplace safety; reducing incident rates, increasing employee engagement and awareness in safety procedures and aiding in optimization of environment, tools and procedures (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015).

However, just like traditional safety programs, BBS programs have weaknesses too. BBS requires a considerable amount of effort if it is to be implemented effectively. The program its success is very reliant on the capabilities of observers to spot and analyse unsafe acts and unsafe environments. Currently, the majority of workers lack the skills to be observers. This will require training costs, so they can acquire the necessary skills. Next to this, usually only the behaviour which is easy enough to detect with the naked eye will be included in safety improvements. This means that observations can result in shallow insights, which in turn will result in basic safety improvements. Furthermore, employee engagement heavily influences peer-to-peer feedback quality, thus heavily influencing the programs their effectiveness (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015). Lastly, the success of BBS is highly dependent on the commitment of managers to the implementation and continuation of the program (HSE, 2007).

A study therefore suggests that the program could use technological reinforcement. The study recommends a tool which could objectively observe and analyse safety aspects in detail, that is easily accessed by the employees and user friendly (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015).

An interview with Cornette, from Dupont Sustainable Solutions, reveals more interesting insights. Dupont is the most experienced company with BBS programs. Their safety observation program, STOP, focuses on observing hazardous situations. They have a leadership approach; teaching supervisors the necessary skills to be able to observe and recognize safe and unsafe behaviours or conditions, and consequently how to communicate feedback. With this approach, communication concerning unsafe acts becomes more open and frequent, and safe behaviour is positively reinforced. Key ingredients for successfully communicating feedback is adding purpose, positivity and potential gain to the narrative. Feedback should make clear why it is important for the receiver to incorporate that feedback into their future actions. The program should encourage support, not a dictatorship. In case workers perform unsafe acts, STOP encourages supervisors to converse with those workers and understand why they are doing it (Cornette, 2020).

Cornette also mentions that BBS requires effort to implement correctly. The main challenge was ensuring high quality peer-to-peer feedback. This involves training employees to both understand and be capable of receiving and giving feedback (Cornette, 2020).

The STOP program has resulted in a 15% decrease in incident rates across all companies. Some companies had an about 50% safety increase (lost time rate, total recordable injury rate, days away rate, worker compensation claims).

Safety always starts with procedures and training. That first layer in safety: protocols, procedures and trainings, are especially effective tools for improving overall safety in warehousing, as the environment has become a quite static one. For a big part incidents are "familiar" by now. (Metselaar, 2020). Procedures and training are the main elements to make the workplace safe and prevent incidents from happening. To make sure these are carried out correctly, supervision is the next element in the safety chain. When all of these fail and the hazardous conditions align, the accident will happen, just like the Swiss cheese model describes (Monis, 2020).

Other types of prevention are stickers close to hazardous elements, reporting systems (of hazardous activities) and well-thought-through work schedules (Monis, 2020).

Another big problem in traditional safety programs is that there are a lot of incidents which are not even being reported. The health and safety manager of a big warehousing company mentions that unreported incidents are a big problem (Monis, 2020). Speculated causes are costs (money, time, reputation) (Monis, 2020) and employee punishment (those who caused the unsafe situation) (Portwood, 2020).

Interviews also support the literature on difficulties that come with observing near-misses and unsafe acts. Small nuances in movements and the vast amount of details make it hard to observe and register unsafe acts or situations (Metselaar, 2020).

Conclusion

Traditional safety is built up in layers, with protocols as the first layer and PPE as the last. The weakness of this programme is that it is focused on lagging indicators (indicators which can be detected once an incident has already occurred). A safety programme which supports traditional safety, by introducing observational methods to identify leading indicators, is behaviour-based safety (BBS). Unfortunately, BBS has its weaknesses too. The programme requires significant effort to implement effectively and will usually result in superficial insights.

A study points towards the opportunity for technological support in safety, to objectively measure safety aspects in a detailed manner.

Manual handling specific safety

The next section of this thesis will go into how companies are currently dealing with manual handling safety issues specifally. In what ways do they try to detect and prevent manual handling related risks.

Training

A method of prevention mentioned in both traditional and BBS programs is (manual handling) training. A clear definition for training is provided below:

"The systematic acquisition of attitudes, concepts, knowledge, rules of skills that result in improved performance at work."
Goldstein (1991) - (Hogan, Greiner, O'sullivan, 2014)

Manual handling training teaches employees how to perform manual handling tasks, to minimize risk of injuries. However, there seems to be a lack of training transfer. This means that the contents of an ergonomic or manual handling training, is not being transferred into daily practice by employees. While the employees receiving the manual handling training understood the training its content and were aware of what was being said, no behavioural change followed. Studies even suggest that there is neither a correlation between the current form of manual handling training and an employee's manual handling behaviour, or the reduction of back disorders (Hogan, Greiner, O'sullivan, 2014).

The current form of manual handling lacks in several areas. 1) Trainings should be customized to fit both the company as well as the individual employees in terms of knowledge, attitude, motivation, experience, intelligence and learning style. 2) Training should be more frequent to maintain an employee's knowledge. A one time training that very rarely is repeated does not ensure the implementation of proper manual handling techniques on the long term. 3) The training should set the right transfer climate. This means they should think about the company its supervision, reinforcement, support, recognition and technical environment. 4) Trainings should also make clear how to properly perform risk assessment of different manual handling situations. This helps the employee to realise, besides knowing how to handle objects or materials, why to do it in a certain manner (Greiner, 2014).

The study suggests there is a need for a way to observe manual handling techniques during work hours, which also takes environmental factors into account. This would be essential for designing effective manual handling training and positively influencing the employees their behaviour (Hogan, Greiner, O'sullivan, 2014).

"These questions really woke me up!" - P (2020)

A warehouse manager acknowledged that manual handling training has never happened in his warehouse, as well as that little attention is given to the manual handling related risks and incidents. The employees themselves also acknowledged that little attention was given to this topic and that the one time they did receive training did not translate into consistent proper manual handling technique.

Task (re)design

Another way of preventing manual handling incidents, is (re)designing the manual handling task. (Re)designing tasks, with the goal of increasing safety, is done by thinking of a task which reduces the exposure to hazards, increases the easiness of working safely and removes obstructions for safe behaviour (OSHA, 2006). Work schedules, training (OSHA, 2006), task description, tools, working environment and employee selection are all part of the task (re)design (HSE, 2007). A task can even be (re)designed in such a way that the improved work task does not require manual handling in the first place (OSHA, 2006).

If tasks simply can not be (re)designed in a matter where no manual handling is required (or it is unreasonably difficult), then the task should be designed in such a way that risk is minimized. Companies are even obligated to do so, by law (OSHA, 2006; HSE 2020). The (re)design of manual handling tasks has partly been described earlier in this thesis (*2.1 Manual handling technique*). However, there also is a tool for calculating acceptable loads for different manual handling activities. A method, called the NIOSH equation was developed, which is widely accepted and adopted as standard. This method allows you to calculate the recommended maximum load weight of a specific manual handling task (Visser et al., 2014; Waters, Putz-Anderson, Garg, 1994). This formula uses the maximum allowed load weight for manual handling and how much this allowed weight will be reduced based on risk multipliers (like load position, task duration and task frequency). The same method includes a formula for calculating a risk index, which indicates the increased risk.
In order to use this method of risk assessment and successfully minimize the risk, certain data has to be collected: Load weight, load location (with respect to the mid-point between ankles), angle of asymmetry, lift frequency and lift duration (Waters, Putz-Anderson, Garg, 1994).

Another study elaborates on the above explained method, by introducing a method for calculating a risk factor for the work conditions (e.g. workplace temperature, load grip and available space) . This formula is used to indicate the duration and frequency of that particular manual handling task could last for, without an increased risk of injury (Visser et al., 2014).

While these methods are meant for the (re)design of manual handling tasks, they could perhaps also be utilized for the detection and prevention of unsafe manual handling through smart technology.

Incident detection

Apart from the observational methods explained in the BBS program, there seem to be no other ways in which current safety programs are able to detect incidents, especially not before they happen. In the construction industry an estimated 80% of the workplace incidents even go unreported and minor incidents only have a report rate of 9% (Paterson, 2015). To add to that, if an employee does develop back pain despite the preventive measures and it is detected, in most cases the origin of the back pain is still hard to track down (Hartvigsen et al., 2018).

There are some products available on the market which help with detection and prevention of manual handling. These will be discussed in subchapter *2.4 Research smart technology.*

The only detection methods for back pain injuries in these sectors is ergonomic training and the occasional observational inspection from supervisors. Ergonomic training however does not intervene when incidents are likely to happen, or evaluate a workers posture during work. Supervisors, on the contrary, are able to intervene and evaluate in this manner. However, it is difficult to keep an eye on every employee all of the time and even if an employee is being observed by a supervisor, the supervisor will not spot every incorrect technique (Monis, 2020)

Conclusion

The current prevention method for manual handling related incidents, training, is proven to have no positive effect on reduction of back-disorders. This is due to lack of frequency, fit, risk assessment content and proper transfer climate.

Through task (re)design the risks involved with manual handling tasks could be minimized or even eliminated. In order to effectively redesign tasks, data on the specific tasks will have to be collected, to evaluate the tasks.

Furthermore, there seems to be a lack in detection methods for manual handling related risks or incidents. The only method (which was discussed earlier in section *2.1 Behaviour-based safety)* is BBS, which had some weaknesses concerning its effectiveness.

Conclusion

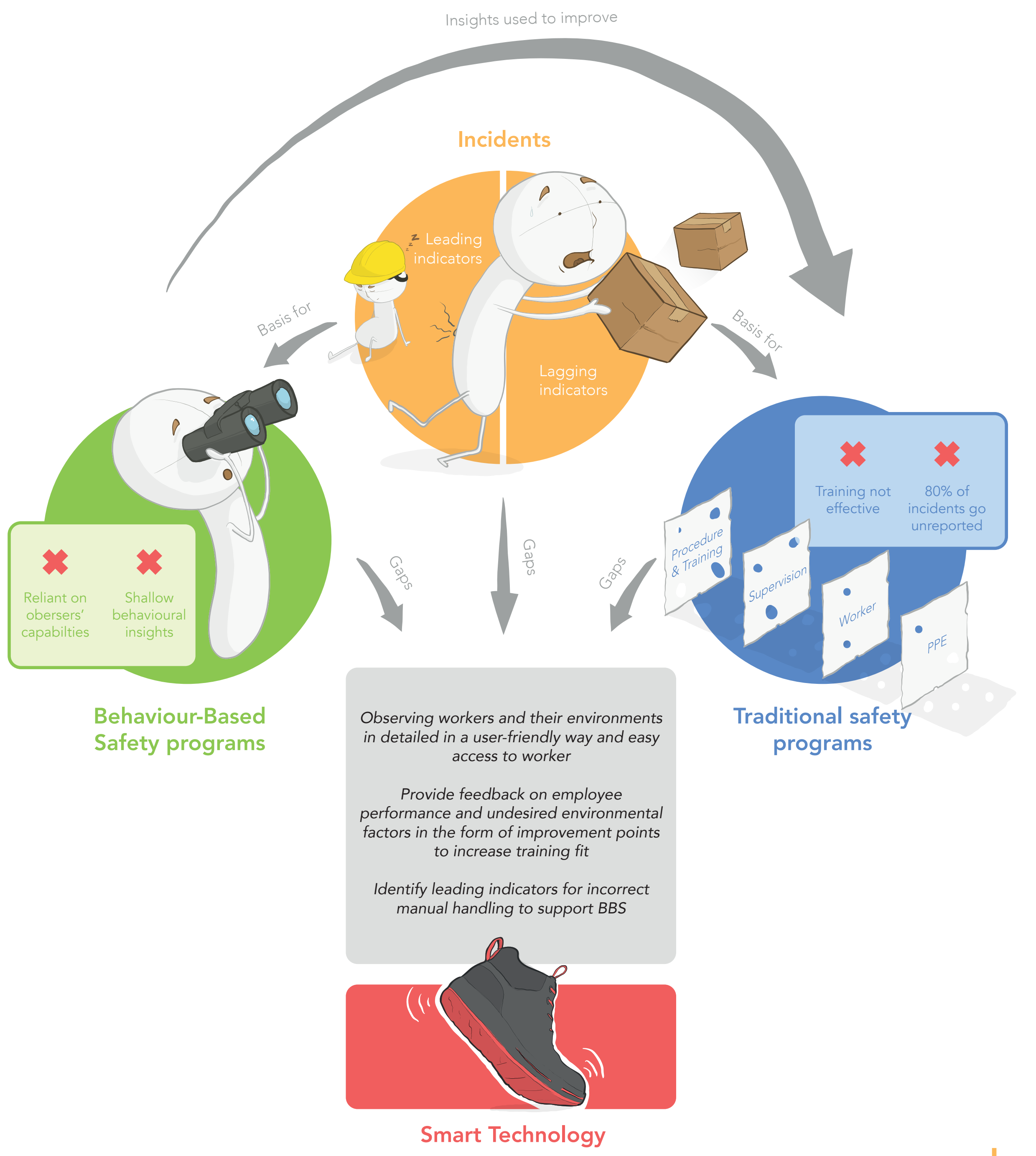
Traditional safety programs are built up in layers. A common safety program starts with procedures and training, then supervision, followed by the worker and finally PPE. A common failure model for these layers is the Swiss cheese model. A problem with traditional safety programs is that they are based on reported incidents their lagging indicators, thus they do not focus on the source of incidents. Next to this 80% of incidents (in construction worksites) are not even reported.

To support these shortcomings, an alternative (and additional) safety program is behaviour-based safety. This program utilizes observation to identify leading indicators (the source of incidents). It aims to use these insights to improve the safety layers mentioned earlier and create an interdependency between employees. BBS is however reliant on observers their capabilities and might result in shallow behavioural insights, as there are small (unobservable) nuances and action-packed workplaces.

Another commonly used preventive measure, manual handling training, seems to have no positive influence on back pain reduction, due to low transfer rates and lack of certain content.

Multiple studies indicate an option for (smart) technological assistance to eliminate weaknesses in today's prevention and detection methods for manual handling.

All in all, detection is difficult and hard to implement correctly, it requires effort and costs and lacks effectiveness because of it. Prevention methods for manual handling are reactive as its built on lagging indicators and training effectiveness seems negligible as it lacks in several areas. Therefore, the current methods for decreasing manual handling incidents have serious gaps in their effectiveness and studies point towards the option of technological reinforcement as a solution. This creates an opportunity for smart shoes to enhance and support current manual handling training



Human behaviour

Human behaviour is an important part of safety. Therefore, it is important to know how behaviour works and how it is influenced. This creates the possibility to design a smart system that can analyse behaviour, improve it and is capable of effectively communicating the outcomes of a smart system its data analysis. For this last part, some knowledge on what makes feedback effective is also required. These topics will be covered in this subchapter.

2.3

Human behaviour

The following section will go into different models for human behaviour mechanisms, as well as discussing what parts of those mechanisms can be exploited to influence behaviour. Lastly it will touch upon the different aspects of effective feedback communication design.

Behaviour mechanisms

There are a lot of different models explaining behaviour (Loketgezondleven, n.d.). As discussed in section *2.1 Manual handling incident causes*, there are two different types of behaviour concerning unsafe behaviour. Unsafe behaviour can either be accidental or on purpose. (HSE, 2007). To further understand this behaviour, different behavioural models will be reviewed.

A commonly used model to explain behaviour from the perspective of behavioural intent (to comply with safety guidelines) is the ASE (Attitude, Social influence and self Efficacy) model (Theory of planned behaviour)

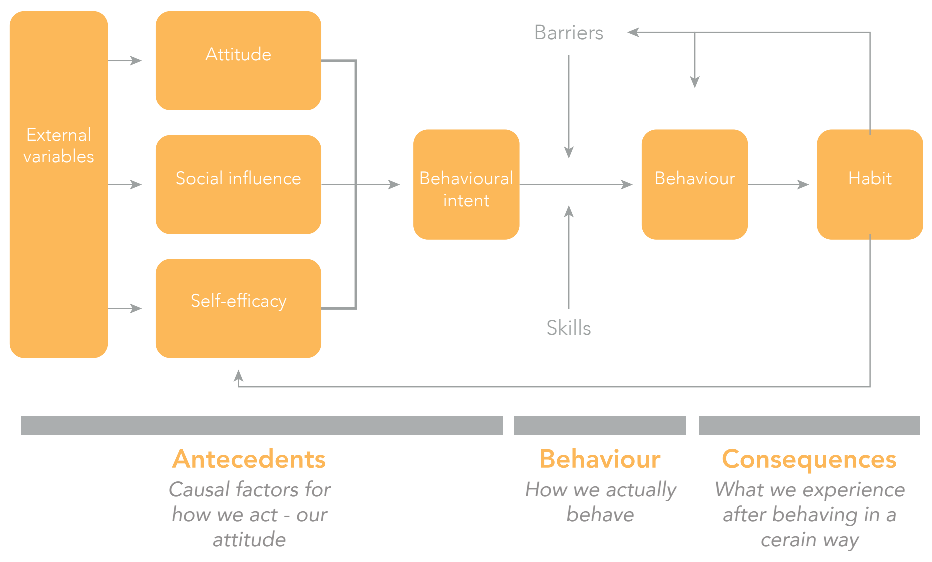


Figure 7: ASE model, by De Vries

by de Vries (loketgezondleven, n.d.). The model, see figure 7, describes that behaviour is dictated by behaviour intent, which in turn is dictated by three psychosocial elements: attitude (the individual's own view on the matter), social influence (perceived norms, social support or pressure and role model influence) and self-efficacy (belief of the individual in its own capability of executing the desired behaviour). These three elements are shaped and influenced by the individual's environment (external variables). The translation from behaviour intent to actual behaviour is influenced by impediments and skills (Bolman Vries, 1998).

Figure 8: Wheel of behaviour, originally by Vlaams Instituut gezond leven (2018)

Later studies suggest that the model needed an expansion: habits. Habits can influence behaviour in multiple ways, either directly or indirectly (by reshaping psychosocial elements) (van Bree, 2018). The incorporation of habits within the ASE model is visualized in figure 7, too. Recently, a new behaviour explanation model was developed. This was due to belief that the ASE model is outdated as it only incorporates rational and planned behaviour, and social environmental influence. The ASE model is still included in this thesis, as it is still a valid model for explaining behavioural intent, it just fails to cover irrational behaviour as well as other environmental influences.

The new behaviour model, the wheel of behaviour (Gezondleven[1], n.d.) (see figure 8), builds on the ASE model. It describes behaviour in a more complete and novel way. The model is a framework of behavioural determinants that can be used as a basis for behavioural change. According to this model, behaviour is made up of three main components: context, competences (knowledge and skills) and motivations. These three components refer to the following questions, respectively:

- Is it possible for the individual to exhibit the behaviour in the given environment?
- Is the individual capable of exhibiting the behaviour?
- Is the individual inclined to exhibit the behaviour?

Each of these main components are, again, made up of, and influenced by, smaller components (Gezondleven[1], 2019).

Behaviour influence design

The (re)design of manual handling tasks has already been discussed (see section *2.2 Task (re)design*) and the organisational goal of creating a corporate safety culture has also already been addressed (see section 2.2 *Manual handling incident causes* and section *2.2 Behaviour based safety*). However, in general, to successfully combat human failure in safety besides the organisation and tasks, the individual's motivations and attitudes should be taken into account too (HSE, 2007; Volksgezondheidenzorg, n.d.). Therefore, it is essential to know how to influence behaviour.

The most effective way of behavioural change is not changing a person, but by changing their environment and perspective on the risks and incidents (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015). Behavioural influence design has varied corresponding models: e.g. stages of change, self-determination, innovation theory, the precaution adoption process model and persuasive by design (Loketgezondleven, n.d.). In addition to this, by investigating the models explained previously (ASE and Wheel of behaviour), leads for the influence of behaviour can be extracted and exploited for behavioural influence design; e.g. looking at how behavioural intent is formed, based on the ASE model, see figure 7, multiple leads for behavioural change can be found: eliminating barriers, increasing skill level or (modifying external factors to) shape psychosocial factors.

To provide a more rigid approach for behaviour change, a structured model for behavioural change is provided below. This approach consists of three steps (Gezondleven[2], n.d.):

1) The first step is to investigate the current behaviour and indicate, in this case, unsafe behaviour as well as the causes for the current behaviour (context, competences or motivations).

2) The second step is identify the desired outcome of the behavioural change and the impediments preventing this change. These impediments can be formulated as a result of the three main components of the wheel of behaviour: What is stopping them from acquiring the required the competences?

3) The third and final step is developing or choosing a technique for behavioural change and developing a concrete plan to implement. It is important to maintain support, and acknowledge and encourage the desired behaviour once achieved (Gezondleven[2], n.d.). Gezondleven presents an entire overview of techniques for influencing behaviour, based on what part of the wheel is causing undesired behaviour (Gezondleven[2], 2019).

Based on the insights from previous sections, it can be concluded that the main behavioural problems within the individual (employees) are knowledge and attitude (see section *2.1 Manual handling incident causes* and *2.2 Manual handling specific safety*). There are a few methods from the overview that are worth highlighting as they cover the mentioned behavioural problems and are feasible to implement using smart technology. The methods which might be of interest for the final design of this project are:

General methods to change an individuals behaviour (Gezondleven[2], 2019).

- Nudging (Small cues which make the desired behaviour the most obvious or easy choice).
- Active learning (activity-based learning)
- Tailoring (tailoring training to the specific needs of a trainee)
- Individualization (training specifically adapted to one individual, through knowledge and pace)
- Feedback (provide insights on how well or what someone is doing and advice on how or what they could improve)
- Reinforcement (reinforcing the desired behaviour through appropriate consequences)

Methods specifically for increasing awareness and risk perception (Gezondleven[2], 2019).

- Consciousness raising (providing insights on situations: causes, consequences and alternatives)
- Personalize risk (inform employees on their own personal risk, based on personal actions)
- Scenario-based risk information (visualize risk in the form of scenarios)
- Framing (visualize the gains or pains that come with certain behaviour)

Methods specifically for increasing skills and self-efficacy as well as overcoming barriers (Gezondleven[2], 2019).

- Self-monitoring of behaviour (promoting employees to keep record of behaviour)
- Provide contingent rewards (rewarding desired behaviour)
- Goal setting (have employees set goals they can work towards)

Communication of feedback

The manner of providing feedback of a smart system its analysed data, especially if the goal is to influence behaviour with it, requires some considerations. There are three important components to feedback (Jasiulewicz-Kaczmarek, Szwedzka, Szczuka, 2015):

- *Medium*
  The medium used in feedback represents the form of the content: visual, textual, verbal, etc. Graphs, text and verbal feedback are the most effective combination.

- *Privacy*
  Feedback can either be private or public. While using both proved to be the most effective, privacy should always be respected (especially for smart technology).

- *Content*
  There are two types of content: summative and formative. Summative feedback indicates what the person is doing and how well he is doing it. Informative feedback provides feedback on how the person could improve on what he is doing. Furthermore, antecedent prompts are key elements in effectively influencing behaviour.

Another type of feedback is warnings. Research shows that only half of people will even notice a warning and only a third will actually comply with them. Some guidelines on effective warning design are to keep it simple (create no opportunity for misinterpretation), have an easy to comply with message (in a reliable and timely manner), have the warning present where the risk is and send the message through a suitable format. To increase compliance, it helps to create a message which displays personal consequence or gain, includes social pressure, feels familiar and is perceived as high risk or high probability (HSE, 2007).

Interviews show that providing feedback to construction and warehouse workers is quite different from providing feedback to management. Content and messages should be simple, concrete and straight to the point. Basically, they should be guidelines which they understand, want to implement and can implement without any difficulty, right away (Monis, 2020).

An interesting project that can be learned from for feedback communication is the Greenroad project. This project utilizes smart technology for the improvement of driving behaviour, and has successfully done so. In the Greenroad project, measured data is being communicated back through the use of a digital interface. This interface, see figure 9, visualizes the behaviour of a truck driver. It provides insights into the safety performance and behaviour accompanied with a concrete overview of their unsafe acts. The model is very reliant on the driver's development of intrinsic motivation. They try to achieve this through providing the before mentioned insights and the continuous reminders of what correct and incorrect driving behaviour is (Portwood, 2020).

To compliment the more quantitative approach, they converse with the drivers to give and gain more qualitative insights, which in turn can be utilized for the improvement of the driver's environment or training (leading indicators) (Portwood, 2020).

Figure 9: Feedback design from the Greenroad Project

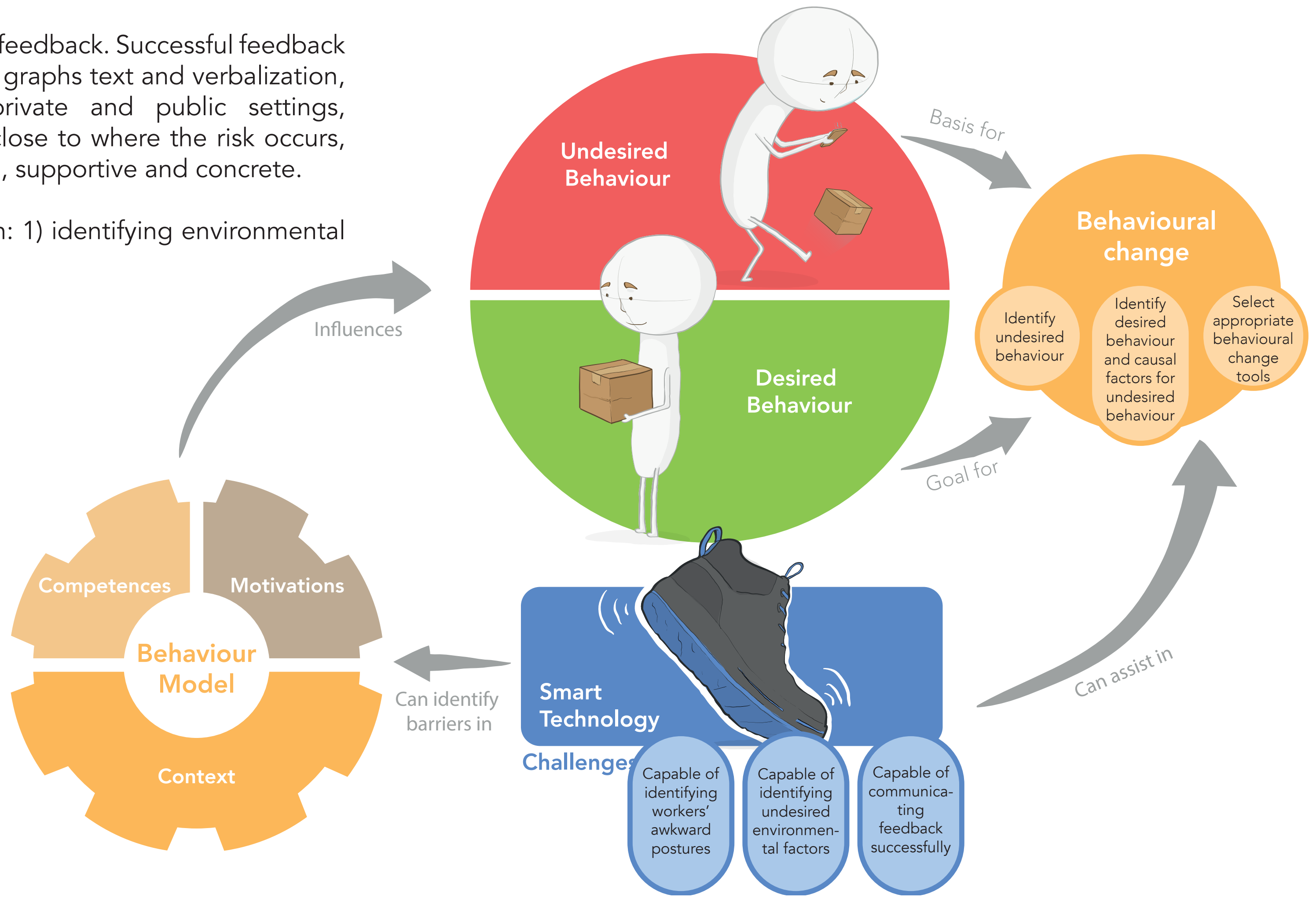
Conclusion

Behaviour can be explained by three main components: competences, motivations and context. These can either be the drivers for desired behaviour or barriers causing undesired behaviour. Changing employees their behaviour comes down to changing their perception of risks and incidents and removing barriers in the three aspects mentioned above. A model describes behavioural change in three steps: identify undesired behaviour, identify causal factors for the undesired behaviour and the desired behaviour it needs to change into, select and utilize behavioural change tools that fit the problem and goal.

An important part for behavioural change is feedback. Successful feedback relies on the following factors: utilization of graphs text and verbalization, antecedent prompts, combination of private and public settings, personalised gains and pains, implement close to where the risk occurs, high perceived risk and probability, positive, supportive and concrete.

Smart technology might be able to assist in: 1) identifying environmental factors, which can be utilized for the redesign of the workers context and tasks. 2) Help workers overcome competency problems by providing insights on their performance and feedback on how to improve. 3) Help motivate workers to behave correctly through the use of for example goal setting or nudges.

In this way, the shoe could potentially, independently from human intervention, aid in increasing correct manual handling behaviour and technique.



Smart technology

This subchapter will cover the fourth body of research required to answer our main research question revolves around technology. In order to know whether implementing smart technology in safety shoes is valuable, it is essential to know whether it is capable of improving the workplace safety system and in what ways.

2.4

Smart technology aspects

The following section will go into what smart technology is and what components are required for a smart wearable device. Furthermore, it will cover the software side of smart technology focusing on the data analysis aspect.

What is smart technology?

With technological trends like smart factories, smart workplaces, industry 4.0, Internet of Things (IoT) and digitalization, the role of (smart) technologies have an increasingly more prominent role in the workplace. To know how smart technology can aid in the improvement of occupational safety, requires knowledge on what smart technology is and what it is capable of. To encapsulate the meaning of smart technology for design, a definition of smart products is given below:

"A Smart Product is an entity (tangible object, software, or service) designed and made for self-organized embedding into different (smart) environments in the course of its lifecycle, providing improved simplicity and openness through improved product-to-user and product-to-product interaction by means of context-awareness, semantic self-description, proactive behaviour, multi-modal natural interfaces, AI planning, and machine learning." (Mühlhäuser, 2008)

Basically, smart technology is a system with sensors, which analyses the measured data to understand a situation and consequently can perform certain activities without the need for human interference. Going from the definition provided above, smart systems can help us to: automate processes, predict future scenarios for advanced decision making, optimize systems, discover new knowledge through ubiquitous sensor systems and more.

Smart technology: wearable components

As the possibility of smart safety shoes is being explored, it is important to know more on what smart wearables are. A smart wearable is a portable device with smart technology, that can be worn on a body and is easy

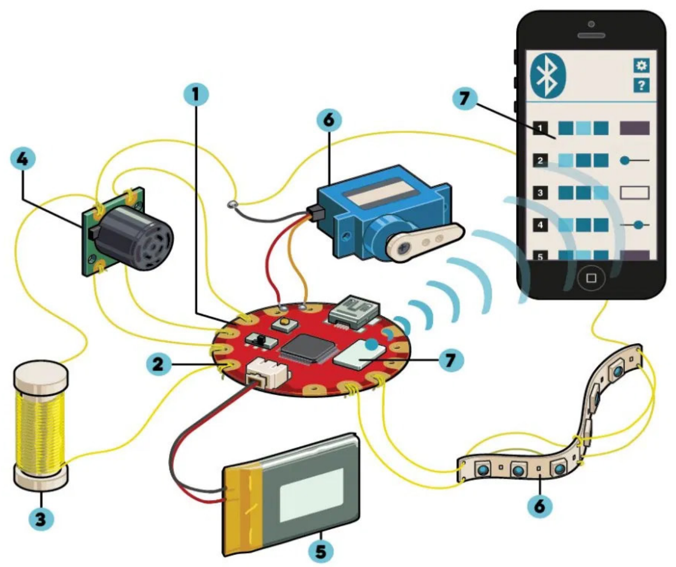


Figure 10: Smart wearable hardware components

and comfortable to use (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016). There are different hardware components that make up a smart wearable. Smart wearables can also include components other then those presented in figure 10, however these are the minimum required components a wearable needs to be a smart:

1) *Controller:*
   The controller, or CPU, component is the brains of the operation. This component is placed on a printed circuit board (PCB), which is the infrastructure of the smart wearable.

2) *Input/Output*
   The input(s) and output(s) are usually part of the PCB. Inputs can receive signals from sensors and can send outputs signals to, for example, actuators.

3) *Conductive textile*
These are conductive materials through which an electrical current can flow. It serves as a connection between all the different components of a system.

4) *Sensor(s)*
Sensors of a system are components that are capable of measuring a certain type of data (e.g. location, acceleration, health data, temperature, etc.).

5) *Power*
The power source of a smart wearable is the container from which all the components draw electricity. This makes sure the system is able to turn on and function.

6) *Actuators*
Actuators are components which can act upon a certain, usually rule-based, signal (e.g. buzzers, LEDs, motors, etc.). This component is not necessarily needed for a system to be smart. The outcome of a system could also be (strategic) advice, which does not require an actuator.

7) *Networking*
In order to communicate data from the wearable to other devices, the wearable needs some type of networking component (e.g. Bluetooth low energy (BLE), NFC, Wifi, etc.) This component is not necessarily needed for a system to be smart, as all potential calculations could be performed internally.

Figure 10 shows how all of these components are connected to each other. It is important to note that there is an interplay between the different components; battery type and size will depend on the electricity usage of the system and if more sensors or actuators are being used, there will have to be more in- and outputs present on the PCB (Lorge, 2015).

Multiple (smart) electronic devices can be set up to form a connected system, or Smart Networked System (SNS). The devices in these systems can communicate with each other to increase the reach and potential of smart devices, which then form a smart environment (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016). These systems can also be referred to as smart environments, intelligent environments or ambient intelligence. A well-thought through definition of smart environments is provided below:

"A Smart Environment is one that is able to acquire and apply knowledge about an environment and to adapt to its inhabitants in order to improve their experience in that environment" (Mühlhäuser, 2008)

Basically, smart environments are capable of sensing the environment and everything in it and consequently is able to improve itself. This improvement is described through many goals like sustainability, efficiency, increasing productivity or perhaps increase safety for its occupants (Appel-Meulenbroek, Brugmans, Kemperman, Dinnissen, 2019).

Software

Next to the hardware, an essential part of smart technology is software. To be more specific intelligent processing of measured data. In order for a smart product to understand its environment, some form of artificial intelligence (AI) is needed (Eifert, Eisen, Maiwald, et al., 2020). A definition of AI is provided below:

"Any device that perceives its environment and takes actions that maximize its chance of successfully achieving its goals"
(Eifert, Eisen, Maiwald, et al., 2020)

There are different methods within AI. One of those methods is machine learning (ML). ML is a method of intelligent processing which can be utilized for the detection of patterns in data. Through ML, machines can learn to identify and recognize relations, associations and patterns. Furthermore, ML allows machines classify data into different categories. An important value resulting from these capabilities, is that these methods allow for the identification of relations that a human would have great difficulty with (if even possible at all). Machine learning comes in three forms: supervised, unsupervised and reinforced learning. In the case of supervised ML, a model is trained by receiving a certain amount of labelled data. Thereafter the trained model is then capable to interpret and "understand" new data. Unsupervised ML refers to a model which receives unlabelled data and subsequently identifies relations or classifies the data into different categories. The last form of ML, reinforced learning, covers models which are trained through a judgement spectrum (reward system): the exact output is unknown, however it is known whether the desired output is good or bad.

Another form of AI, and a subset of ML, is a neural network (NN). NNs are inspired by the same principle as the human brain. These networks are a form of intelligent processing where a set of data input categories (nodes) are known, as well as the data output categories, but the relations between those two are not. These relations are referred to as the hidden layer, which are a set of algorithms. A more advanced form of NNs is deep networks, which is basically are NNs, except they contain multiple hidden layers, which allow them to handle more complex problems.

An important aspect to note is that the development and training of these models require significantly more computing power than the implementation of models. Therefore, the training of these models should be performed on a computer.

A risk involved with intelligent processing is overfitting. Overfitting means that a model is trained on biased training data, which makes it work perfect on the training data, but once new data is entered in the model, it fails to interpret it correctly (van der Vegte[2], 2020). Therefore, this is an important consideration for the prototyping phase of the development of a smart product.

Speaking with van der Vegte (2020) revealed interesting insights. As training models requires more computing power, it is not ideal to implement this feature in smart wearables. More computing power means more electricity and a more powerful CPU. This will influence a smart wearable its weight, price and battery life negatively.

Furthermore, van der Vegte (2020) outlined different ML methods, like classification (supervised ML, able to categorise data) curve- and function fitting (data prediction), sequence mining (unsuperfvised ML, identification of patterns) and market-basket analysis (unsupervised ML, categorising).

Lastly, it is recommended to first attempt setting up an expert-system analysis, which is basically a set of rational rules generated by experts. This is cheaper, faster (and might require less set-up effort) than ML (van der Vegte, 2020).

Conclusion

Smart products are products which are capable of measuring and sometimes even "understanding" their context. Thereafter it is capable of taking certain actions without the need for human interference. These products usually consist of a set of components: controller, input & output, conductive textiles, sensor(s), power, actuator(s) and a wireless module. When multiple of these products are set up in a network, they can create smart environments, which increases the potential of each product into a network capable of measuring and "understanding" an environment. Subsequently, it can optimize the environment based on a number of given goals.

Lastly, smart technologies also consist in data analysis, intelligent processing. AI, ML and NNs allow for classification of data inputs and the identification and recognition of complex relations, associations and patterns between different inputs and outputs (even if they are incomprehensible for humans). Translating this knowledge to previous chapters, intelligent processing could help identify relations between measured data and manual handling technique, as well as possibly predicting manual handling related risks or incidents.

Smart technology in occupational safety

In order to know how smart technology can impact occupational safety, this section will cover other applications of smart technology, including both a more theoretical (uses and frameworks) and practical (other smart products) perspective. Lastly, this section will cover a vital aspect of smart wearable implementation: user acceptance.

Applications

Some of the main applications of smart technology were already mentioned in the beginning of section *2.4 What is smart technology?*. However, applications of smart technology for occupational safety are still quite varied. The principles behind these applications, however, come down to the following: Information support, real-time control of protective and comfort-related PPE properties, continuous measurement of environmental conditions, human activity-, health- and physiological status monitoring (real-time health monitoring), performance enhancing, continuous inspection of workplace and tools, high-risk zone detection (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016).

Next to smart devices there are also smart materials, which can for example generate electricity, with optical, mechanical or thermal input (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016). This electricity could expand battery life significantly (or eliminate charging as a necessary separate action all together), which subsequently increased usability.

While all of the previous applications have great potential for smart PPE, the focus of this thesis is on manual handling related safety. Looking into applications for this territory, a study also sees great potential and value for smart technology to aid in the prediction and prevention of occupational risks in construction related to musculoskeletal disorders, which can be caused by manual handling (see section *1.1 The Problem*). One reason for this potential is because workers already wear PPE, which form a perfect basis for the implementation of smart technology. Introducing smart wearables in this manner would not hinder the worker's work tasks in any way and therefore maximise the wearable its usability (Choi, Hwang, Lee, 2017).

Another study shows that awkward body postures (incorrect manual handling body postures) all have unique plantar pressure distributions (PPD) (weight distribution in feet). The study also shows reliable methods of detecting and identifying these awkward body postures through these PPD profiles, using supervised machine learning (classification) (Antwi-Afari, Li, Yu, Kong, 2018). Figure 11 shows five examples of awkward body postures that correspond to different PPD profiles.

Other attempts at exploring the possibilities of implementing (smart) technology in shoes, to measure body posture, show promising results. Examples of these are the Sensistep (Leihitu, 2017), Gymsoles (Elvitigala, Matthies, David, Weerasinghe, Nanayakkara, 2019) and another foot mounted sensor system for body tracking (Nino et al., 2019). Next to this, also other wearables exploring the possibilities of detecting incorrect manual handling are being developed (e.g. the VITinitiative) (Chan, 2018). These early attempts show promising results for the feasibility of smart wearables preventing manual handling induced risks using PPD profiles.

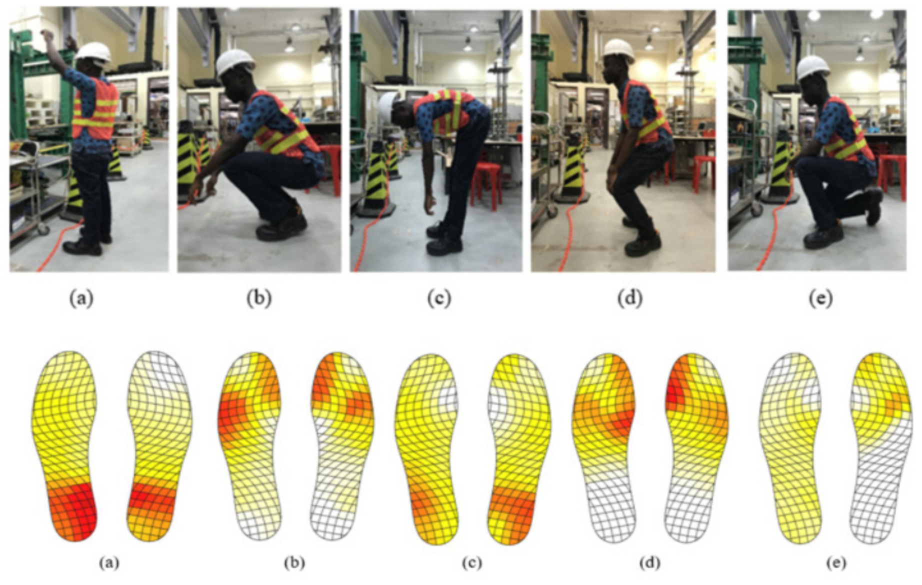


Figure 11: Awkward postures with their corresponding plantar pressure distribution profiles (Antwi-Afari, Li, Yu, Kong, 2018)

Smart technology has also been used to compliment BBS programs. An example of this is the Greenroad Project (GRP). The GRP is a product-service-system that enhances safety for truck drivers by focusing on their bad driving behaviours and reducing this as much as possible. They do this by implementing smart technology in the trucks, which records all kinds of data about the truck its driving behaviour. Sensors measure (and "feel") things like acceleration, braking, turning, common motor while standing still, location and speed. Next to the truck its own data (this includes vehicle characteristics and specifications) it also takes the environment into account (e.g. commonly unsafe crossings, incidents and roadwork). From all this data the company then presents the data in an infographic-style way (see section *2.3 Communication of feedback*) to the drivers as well as their supervisors. Then the drivers can intrinsically improve their behaviour or the supervisors can set up a conversation to talk about bad driving behaviour (Portwood, 2020).

Based on different analysis techniques, the smart system is capable of incident prevention on both short (rule-based analysis) and long term (trend analysis, big data) (Portwood, 2020).

There already is a product on the market which tries to increase manual handling safety, the Arc (see figure 12). An interview with Chan (2020), the CEO of the company behind the product resulted in more detailed knowledge on the smart product. The Arc is a small smart wearable which can be clipped on the back of your t-shirt and thereafter can measure manual handling technique. The product is capable of measuring four distinct indicators for manual handling incidents: bending of the back (forwards and backwards), axial twisting of the torso (relative to the hip), lateral bending of the back (side to side) and prolonged (awkward) postures.

The development of the product utilized machine learning to identify relations between the product its measured data (gyroscope and accelerometer) and the different risk indicators. Subsequently, it is able to detect the risk indicators based the data measurements. This is much like the PPD profiles discussed earlier in this section.

The product uses an actuator (buzzer) in the device to alert the wearer of incorrect manual handling technique, and provides a more detailed overview at the end of the day through a digital interface.

While the product has shown great potential (45% reduction in unsafe manual handling acts, 35% reduction in MSDs), it is also facing issues. First of all, the product only focuses on a few lagging indicators (correcting incorrect manual handling), while true potential lies in the leading indicators (what causes incorrect manual handling). Second, *chapter 1 Introduction* reveals significant issues with non-compliance with PPE, which is also an issue for the Arc as it is an extra component in the daily routinesof workers.

Figure 12: Arc - smart product for inscreasing manual handling safety.

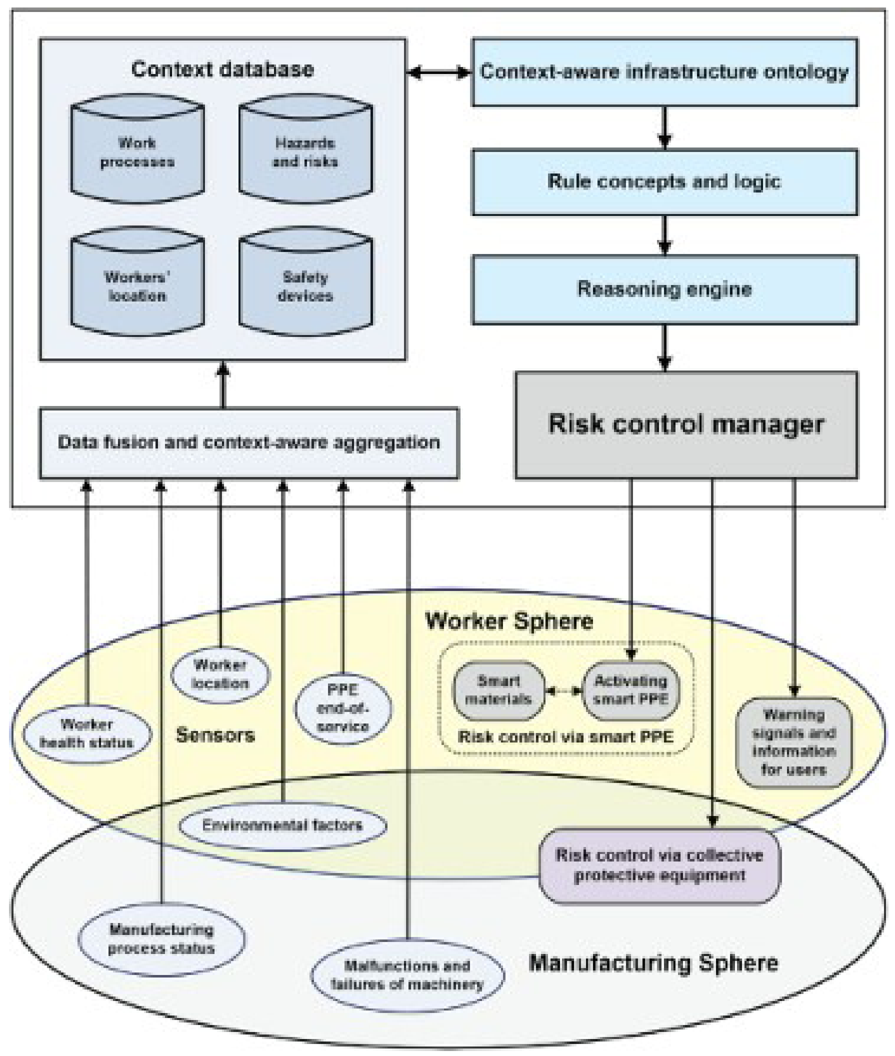


Figure 12: Framework for a smart environment focused on safety in construction (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016)

Impact on safety programs

With the uprise of smart worksites (smart environments implemented at worksites), the environment and tasks of workers will become increasingly more varied, at a faster pace too. With that, the risks involved in the process, too, will be more varied and at a faster pace. This makes it harder to predict risks using traditional methods of risk assessment. This, therefore, decreases the effectiveness periodical risk assessments. Because of this, there is a need for a new way of performing risk assessments, suitable to the ever growing complexity and pace of worksites (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016).

A study pointed out that smart technology could potentially fill the previously described need (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016). There are two main reasons mentioned.

1) Smart technology could transform periodic- and manual risk assessment into continuous-, automated- and real-time risk assessment. All of the different elements which are important for risk assessment (quality of tools and workplace, capabilities of employees, traffic routes, etc.) can all be measured with sensors and analysed in real-time instead of periodically.
2) Smart technology could transform group risk assessment into personal- and individual risk assessment. Current safety programs assume employees with similar work tasks to have similar risks, which will not be sufficient in every case as generalised risk will not be accurate for everyone. As smart wearables allow for monitoring of an individual employee's data, this allows for the personalisation of risk assessment and with that the personalisation of incident prevention.

A new framework for risk assessment was developed, specifically for smart worksites. The framework, seen in figure 12, describes a system of how smart technology could be set up in a worksite to increase safety (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016). The framework is made up of sensors which monitor the environment and everything in it, a system (reasoning engine and risk control manager) which analyses the measured data (context database) and actuators, which are able to perform actions to mitigate any detected risk.

With this framework, it would be possible to reach ubiquitous occupational safety. This means that by implementing a sensor system which is embedded within the worksite on such a level that it is covering every aspect in every way (e.g. all objects, employees and working conditions are being measured) and if the sensors were to be fully incorporated, in a logical, accepted and user-friendly way, an all-sensing, "fail-safe" safety system can be created (Podgórski, Majchrzycka, Dąbrowska, Gralewicz, Okrasa, 2016). However, new problems are likely to be introduced to the system (e.g. failing hardware (sensors)).

User acceptance of smart technology

In 2017, only 9.6% of construction workers is using a wearable technology, while 97.6% use smartphones (Choi, Hwang, Lee, 2017).

A factor which might hinder the adoption of smart wearables is data privacy. Smart wearables usually record personal information, which on the one hand is sometimes necessary to function but on the other hand the user might feel spied on (Choi, Hwang, Lee, 2017).

A study done on the adoption of smart wearables in construction states that the workers their intention to adopt is closely related with perceived usefulness, social influence and the perceived privacy risk. Next to this, the study shows that an employee's experience with wearables will increase the employee's perceived usefulness of new smart wearables and therefore, increase the intention to adopt. Other factors which can help with adoption of smart wearables is the ease of use and a focus on leadership (introduce a foremen that has already adopted the technology) (Choi, Hwang, Lee, 2017).

In the warehousing industry there is an even bigger rise in technology. The warehousing automation market was evaluated at around 45 billion dollars and is expected to grow with a factor of three by 2024 (Zion MarketResearch, 2018). Other technology like autonomous vehicles, machine learning and virtual reality are also being developed and partially used (Nassar, 2020). Next to this technologies for harbours being developed to ensure the 1.5 meters distance (van Miltenburg, 2020).

Dhall (2020) mentions some familiar concepts, one of which is user acceptance. User acceptance is an important part of smart systems, for example due to perceived privacy risk, as the user can feel spied on. Therefore, usability has to be increased, to either outweigh or explain data collection (high user-friendliness, high perceived usefulness, no hinder in work tasks).

Furthermore, components in a smart system need to have either the internal computing power to analyse the data itself, or contain data transmission technology (Lora or Bluetooth) so that this can take place elsewhere. This data analysis, depending on how complex the calculations get, will probably need to be outsourced to a capable company (which in case for Allshoes, is true). The complexity of these calculations also are tightly connected to the frequency of the feedback loop; more complex calculations take more time. In addition to this, another important factor for the feedback frequency is the need for a certain feedback frequency. Trend analysis does not need to be communicated back to the user in real-time. The last point Dhall addresses concerning data analysis is to pay attention to the data filtering system (what to take into account for the analysis and what not) (Dhall, 2020).

Lastly Dhall provides hardware related advice for implementing smart technology in a shoe. Flexible PCBs can help to increase comfort in the shoe and increase durability of the PCB. Furthermore, modularity of the electronic components in the shoe is only worth it if the electronics inside are more expensive than introducing a modular system. Lastly, the most important (hardware) stage of development of a smart wearable is the prototyping phase. This reveals the most insights on what will or will not work. A more theoretical approach will result in a considerably longer development duration including just as much (if not more) uncertainty throughout the process (Dhall, 2020).

There is an increase in technology within this sector. In a study performed by Ernst Bouma, it was found that the workmen in the construction sector started to shift their perspective on technology over the years. Where at first an I-pad on the worksite seemed strange, it is now fully implemented with their full support (Bouma, 2020). Now the construction sector is using technology like drones for inspection, I-pads for work tasks and virtual simulation for precisely planning out a whole construction project to the last detail (de Vries, 2020; Bouma, 2020).

Corona-crisis has also helped a lot in acceptance for digitalization and other technological trends (Burink, 2020). Enormous companies and industries were able to transform their entire workspace into a digital environment, by working remotely (Glover, 2020). Employees (construction) do not want tools which allow them to perform heavier tasks. They want the tasks to be eliminated in the first place (Bouma, 2020)

Coming back to the GRP, challenges the GRP faced with implementation is the GDPR (privacy laws). To combat this they did three things: 1) Communicate the purpose of the project. 2) Make the collection of data as transparent as possible (employees can see all the personal information which is being collected from them). 3) Make use of the sheep method (e.g. 80% of drivers already have a green score) (Portwood, 2020). This comes from the principle which is implemented in hotels: "80% of the people in this hotel reuse their towel" (Goldstein, Cialdini, & Griskevicius, 2008). Notice that these three principles are in line with what the literature on user acceptance: 1) Perceived usefulness. 2) Perceived privacy risk. 3) Social influence.

Conclusion

Smart technology has numerous applications. An interesting one is the detection of awkward body postures based on PPD profiles (through utilization of ML in the development process). This same principle, of setting up data profiles with ML (classification) with data collected by a smart product, which is thereafter able to detect awkward body postures, has been proven to work in a product called the Arc.

An important factor is the social aspect of smart technology: user acceptance. Studies show user acceptance is influenced by perceived usefulness, perceived privacy risk, social influence and previous experience with smart wearables. A suitable medium to implement smart technology in, for occupational safety in warehousing and construction, is PPE. PPE is already obligatory worn at the work site and thus would interfere little to nothing with the wearer's daily work tasks.

Furthermore, smart technologies allow for a fundamental change in the current risk assessment of occupational safety. First of all, periodic risk assessment can be changed into continuous and real-time. Second, group risk assessment can change to individual and personal. This, together with the non-obtrusive characteristics of smart PPE, show potential in supporting the shortcomings in BBS programs. The challenges presented in *section 2.2 Behaviour-based safety*, to objectively observe in detail, in a user friendly manner, are made possible through smart PPE.

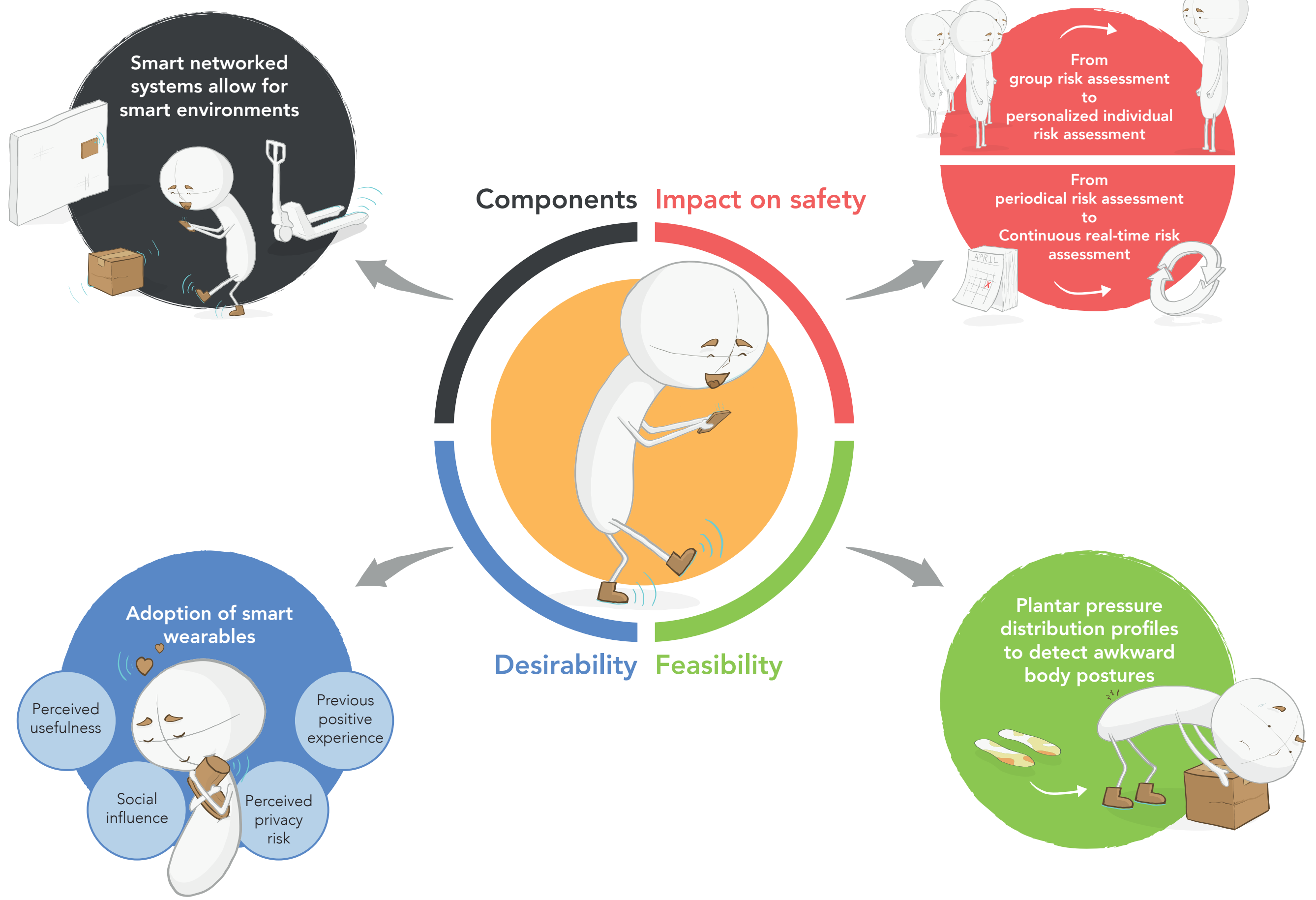
Conclusion

Smart technology is a system with several technological components which are able to measure, analyse and even "understand" a situation and can perform certain activities based on this information without the need for human interference. When connecting multiple nodes of smart technology it creates a smart environment, capable of understanding and manipulating an environment to improve this environment.

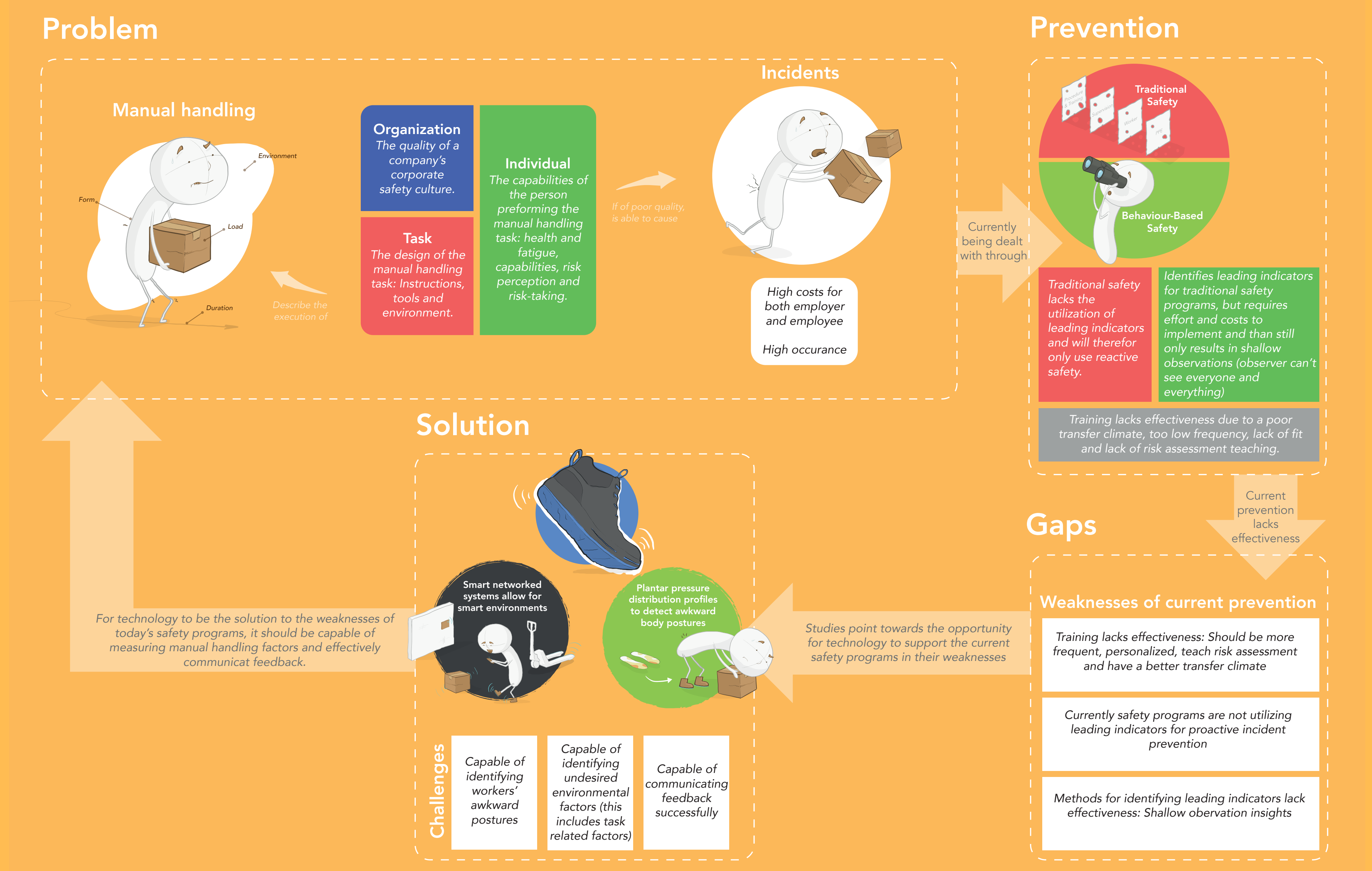
Acceptance and adoption of smart wearables is influenced by four factors: perceived usefulness, perceived privacy risk, previous experience with smart wearables and social influence. Perceived usefulness suggests that smart PPE is even more likely to be adopted than other wearables, as they are already part of the worker's daily routine and would not cause any hinder.

Technology its ability to assist in manual handling safety seems promising as different awkward body postures correspond with different plantar pressure distribution profiles and the technological feasibility of measuring these profiles has been proven in several design research projects.

Implementing smart safety technology in construction and warehousing creates the possibility for continuous, real-time and personalised individual risk assessment, instead of group and periodic risk assessment. These qualities show potential to support the safety weaknesses presented in the workplace safety section (see section *2.2 Conclusion workplace safety*).



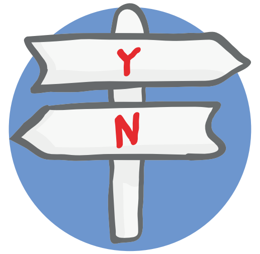
Research: conclusion



Design

This chapter will cover the design part of the thesis. The goal of this chapter is to illustrate a possible solution which has the right capabilities to fill the current gaps in manual handling related safety. It showcases the product itself and a strategy which is build around the product. in order to do so the chapter will cover the design scope, the final design, the business context and strategy.

3

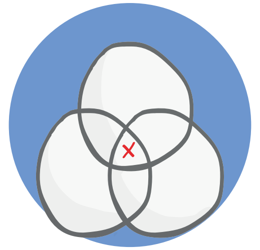


1 Design scope

This subchapter will go over the guidelines which will be considered in the design process. This subchapter serves as a starting point for the design process and evaluation sheet for the final design.

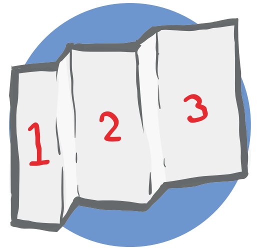
2 Final design

This subchapter showcases the final design concept. It cover the working principles behind the product and service, give a first draft of the possible aesthetics of the shoe and ends with the value behind the product. The purpose of this subchapter is to explain what the final design, how it works and why its a valuable concept.



3 Business context

This subchapter covers the viability, feasibility and desirability of the final design. The purpose is to illustrate the market potential for this product and show that it is possible to manufacture and implement.



4 Strategy

The last subchapter of this chapter will provide information on the strategy behind the final design. The purpose of this subchapter is to illustrate the strategic value of the final design.

Design scope

To lead the conceptualization of the design process a more detailed design scope has been set up. This section will go into the different guidelines that will need to be taken into account for the conceptualization. Some of these are constraints that need to be worked with, others are wishes that just need to be considered. Creating a design scope will help with the translation of research to final design, lead to more significant designs and make sure company requirements are met.

3.1

Design scope

The design scope serves as an overview of guidelines that should be considered or be abided by in the design process. The following section will go into the different implications for design that came forth out of the research, what the design goal is and provide a programme of requirements (and wishes).

Research results discussion

Looking at the research conclusions, the final design should be capable of identifying and detecting leading and lagging indicators for manual handling related incidents, as these are fundamental for the prevention of these incidents. Lagging indicators allow us to implement reactive prevention (e.g. detection of awkward body postures) and leading indicators allow for proactive prevention (e.g. detection of task design flaws). Based on the manual handling technique research in *section 2.1 Manual handling technique*, a list of these different indicators has been compiled (see appendix A).

According to the research, human factors play a significant role in incident causation and should be taken into consideration. The three different human factor elements (the task, the organisation and the individual) can serve as key players in the prevention of incidents (e.g. implementing insights on leading and lagging indicators in these three areas).

The current safety programs have shortcoming in their ability to detect and prevent incidents. This presents an opportunity to support the current safety programs. Insights on leading and lagging indicators can be utilized to reduce or even eliminate their shortcomings: Traditional safety programs (lack in leading indicators utilization), behaviour-based-observation programs (lacks capability to observe accurately and ubiquitously), manual handling training (lacks frequency, personalisation, risk assessment knowledge and a proper transfer climate).

Furthermore, pressure distribution profiles seem to be the most promising method for (awkward) body posture detection indicated by the conducted research. This is due to it being a novel method, including innovative data analysis techniques (intelligent processing) and as it can all be implemented within a shoe.

Other implications for design

Allshoes has determined that the solution should be a shoe or at least be focused around the shoe. This means that it can be a service, or something other than a shoe, as long as the shoe is an indispensable part of that solution. In addition to this requirement, it is preferred (by the company, Allshoes) that the shoe should be part of the RedBrick product line. RedBrick is a safety shoe company which is owned by Allshoes themselves and is recognized as a progressive brand for their stylistic approach (Arts, 2020), which makes it a suitable brand for an innovative smart safety shoe.

In terms of shoe characteristics, an interview with Dirksen (2020) revealed that preferably the safety shoe would be an S3 certified shoe. S3 is a safety quality type which is required for construction. Therefore, if chosen for an S1P class safety shoe, huge market potential will be lost. Furthermore, the shoe should not include a waterproof membrane. This would not be a requirement for the targeted sectors (Warehousing and construction) and would only decrease the breathing quality of the shoe, making it less desired in the target segments (Dirksen, 2020).

Design goal

Based on the previous paragraphs, a design goal is formulated:

> ***Design a product or service which either is or fundamentally needs a safety shoe, that is capable of identifying and detecting leading and lagging indicators for manual handling related incidents and is able to implement these insights to reduce or eliminate the shortcomings of current detection and prevention methods by focusing on the organisation, the individual or the task.***

Programme of requirements

The following section will dive deeper into the different criteria which are of importance for the evaluation of solution ideas. There are not exact measures given for each criterion as they have an interplay with the final design its value; if a solution offers enough value, requirements can be considered with more freedom; there are no hard constraints.

The existence and importance of different criteria are extracted from interviews (stated behind the criteria titles). The roles of the different interviewees are listed in the references. After the full list of criteria was completed, the list was discussed and assented with, in terms of weight (see appendix C) and completeness, with an H&S manager (Monis, 2020).

Generic criteria

The generic criteria are the most important criteria, which serve as a quick overview of an idea its strategic value. The importance of these three criteria is based on the innovation sweet spot (Sonderegger, 2020), essentially the three criteria in this group are essential components for a successful innovation product (or service). The detailed criteria, discussed next, influence the overlooking criteria and are therefore considered separate. For example, lower weight means a more desirable product and more generalizability leads to a higher viability.

Feasibility
Feasibility describes the possibility to produce the product or service that an idea describes. This covers the technology and manufacturing of the product or service, but also social, physical or psychological limitations (e.g. ergonomics or social adoption). A last factor of feasibility is the company its capabilities, resources and brand. The company has to be able to allocate the capabilities and resources for the development and production, as well as have a brand fit with the solution idea.

Viability
Viability concerns the possibility to generate profit with a solution. This could potentially be indirect revenue (e.g. boost sales of other products).

Desirability
Desirability refers to how likely it is for the targeted market segment to want the product or service. The bigger the expected need from the market, the higher the desirability. Examples of characteristics that generate desirability are fulfilling a need which has no other ways of being fulfilled, or having a product or service which fulfils a need in a better manner than competitors.

Detailed criteria

These are the criteria that matter specifically for this project. Together they matter just as much as the general criteria, however individually they have less of an impact on the attractiveness of an idea.

Weight (Monis, 2020)
Weight is an incredibly important factor in the decision of what shoes will be bought. In some cases this could even be leading for decision making. This will not come down to a few additional grams, however, a few hundred additional grams definitely will.

Price (Monis, 2020)
The price of smart safety shoes might get compared to other safety shoes. An increase in price will have to be justified. This factor matters more if the client is smaller. The bigger the company and the bigger the value, the less price matters.

Privacy (Metselaar, 2020)
As smart devices work with data streams, privacy will be a concern. The data that is being collected and used should be legal and performed in a legal manner. However, privacy is a sensitive topic and even if the collection of a certain type of data is legal, this does not mean it is accepted. Therefore, social acceptance should be taken into account. This criterion is not a "make-it or break-It" one, as there are plenty of ways to make it work (e.g. data anonymity or make it an obligatory part of the job). However, difficulties with privacy laws make a concept less attractive.

Shoe-spotlight (Arts, 2020)
Allshoes is a safety shoe company. Although they have shown to be flexible in their offering, their core offering is safety shoes. If the shoe is not an important part of the solution, it is less suitable for the company. If the same solution can be done with a smartwatch or other tools, the value, of having that technology in a shoe, decreases (as a competitor might start to offer exactly that).

Impact on costs (Monis, 2020)
Another part of the core value of the product is the decrease of incident related costs. If the incident type relates to a high quantity of costs, it has a higher potential of cost reduction, thus increasing the impact of the product. The main reason for wanting to increase safety, next to the health and well-being of employees, is to reduce the amount of costs that come with it. This makes this an important criterion.

Scalability (van Kempen, 2020)
This criterion concerns the possibility of sales rate growth in case more resources are allocated towards the solution. If the product or service forces the use of immature technologies, scalability becomes a problem, decreasing attractiveness.

Influence of culture on results (Burink, 2020; de Vries, 2020)
Culture can prevent change, especially when it concerns behavioural change. The product could be set up and presented In such a way that it will be less influenced by culture, which decreases the importance of the criterion. However the harder it is to do so, the less attractive the product or service will be.

Future-proof (Arts, 2020)
This criterion concerns the market sustainability of a product. In case future scenarios renders the current version of a product or service useless, the product or service should be flexible enough to adapt to the situation (e.g. apply the hardware, software or system to a different problem). Next to this, if it is easy for new entries in the market to take over, the product or service becomes less future-proof. If a direction is more likely to have solutions that are future-proof, it makes the investment into it more worth it. Thus making the direction more attractive

Reliability (Monis, 2020)
The production quality and used technologies should be reliable. If the user cannot fully trust the product on performance and results, it will not be adopted (Monis, 2020). Therefore, being forced to use immature technologies, unsuited materials, fragile construction or a poorly thought out production plan will decrease the attractiveness of the direction.

Sustainability (Arts, 2020)
Sustainability refers to the possibility of a product to be recycled. If products are not fully circular, their negative environmental impact should be as low as possible (e.g. long lifespan or modularity of components).

Generalisability (Arts, 2020)
Generalisability concerns the ease in which the product can be used for more than one person, one location, one company, one sector or one country.

Multi-value-solutions (Riemsdijk, 2020; Arts, 2020)
Multi-value means whether a product or service has multiple values that it offers. A solution that, next to its main value (e.g. safety), also offers other values (e.g. increase performance or optimize processes). This is not an important criterion as it is not the main focus of this project. However, if the product is able to have multiple values it has more leverage to communicate its worth to the executives of companies.

Impact on safety (Monis, 2020)
This criterion focuses on the performance of a product or service. The bigger the positive impact on safety, the higher the performance of a product or service, increasing the attractiveness. Factors which play a role in this are the type of incident that is being prevented, its frequency and what percentage of that incident type is being prevented. This criterion is one of the most important ones as it is the main focus of this project and the biggest value the product should offer.

Final design

This subchapter will showcase the final design, highlighting its features, functionality and value. The working principles behind the data collection, analysis and feedback are discussed to illustrate the final design its methodology.

3.2

The design

This section will go into what the final design is, what the different components in the smart safety shoe are, and the methodology the shoe utilizes (how it measures and eliminates causal factors).

The final design is a concept for a smart safety shoe which is capable of identifying leading and lagging indicators for manual handling related incidents and thereafter is capable of effectively communicating insight to eliminate these causal factors.

Smart safety shoe components

As seen in figure 14, the smart safety shoe is made up of several technological components: Pressure sensors, LEDs, a rechargeable battery, a PCB (including CPU), a 6-axis IMU (inertial measurement unit) and a wireless module. Most of these components will be located in an insole. For the reasoning behind the location choice for the sensors, see *section 3.3 manufacturing feasibility figure 27.*

Besides the technological components mentioned above, the smart safety shoe has a mechanical component: the BOA laces. I chose to include this type of lacing as it has increased in popularity rapidly. The number of sales (within Allshoes) increased by 400% over 2.5 years (Woltheus, 2020). Other reasons for choosing BOA laces is that they fit in the futuristic aesthetics of the shoe and the fact that they were the most desirable type of lacing that came forth out of the interviews with warehouse employees.

Figure 13: Drawn mock-up of the potential aesthetics of the smart safety shoe.

Other features of the shoe are similar to the current features of Redbrick shoes. First, toe and heel protection increases shoe durability (as these parts of the shoe wear quickly due to the way in which they are being used (de Bruyn Kops, 2020)). Second, the shoe has the standard safety components like a composite toecap and an anti-perforation kevlar sole.

As the smart shoes are running on rechargeable batteries, they need to be charged from time to time. The smart safety shoes will include a wireless charging station where the shoes can be docked in at the end of the day. Next to this, the shoe will have a smart power on and off system. Whenever the shoes detect they are being worn (pressure detection and inertia) they automatically turn on. Once they detect they are taken off, they will automatically turn off. This could potentially even be implemented in a more elaborate fashion: turn off in breaks or even in between tasks (As long as it does not interfere with the shoes their functionality).

Smart safety shoe aesthetics

The aesthetics of the shoe are based on three different styles: Redbrick, techwear and futuristic. The development of a first drawn mock-up has been made with the aesthetic traits of these three styles in mind. The aesthetics of the shoe are not set in stone and will need more exploration and validation. However, the shoe was acknowledged as a promising first look into the futuristic style (de Bruyn Kops, 2020). A breakdown of the aesthetics styles is provided in appendix B.

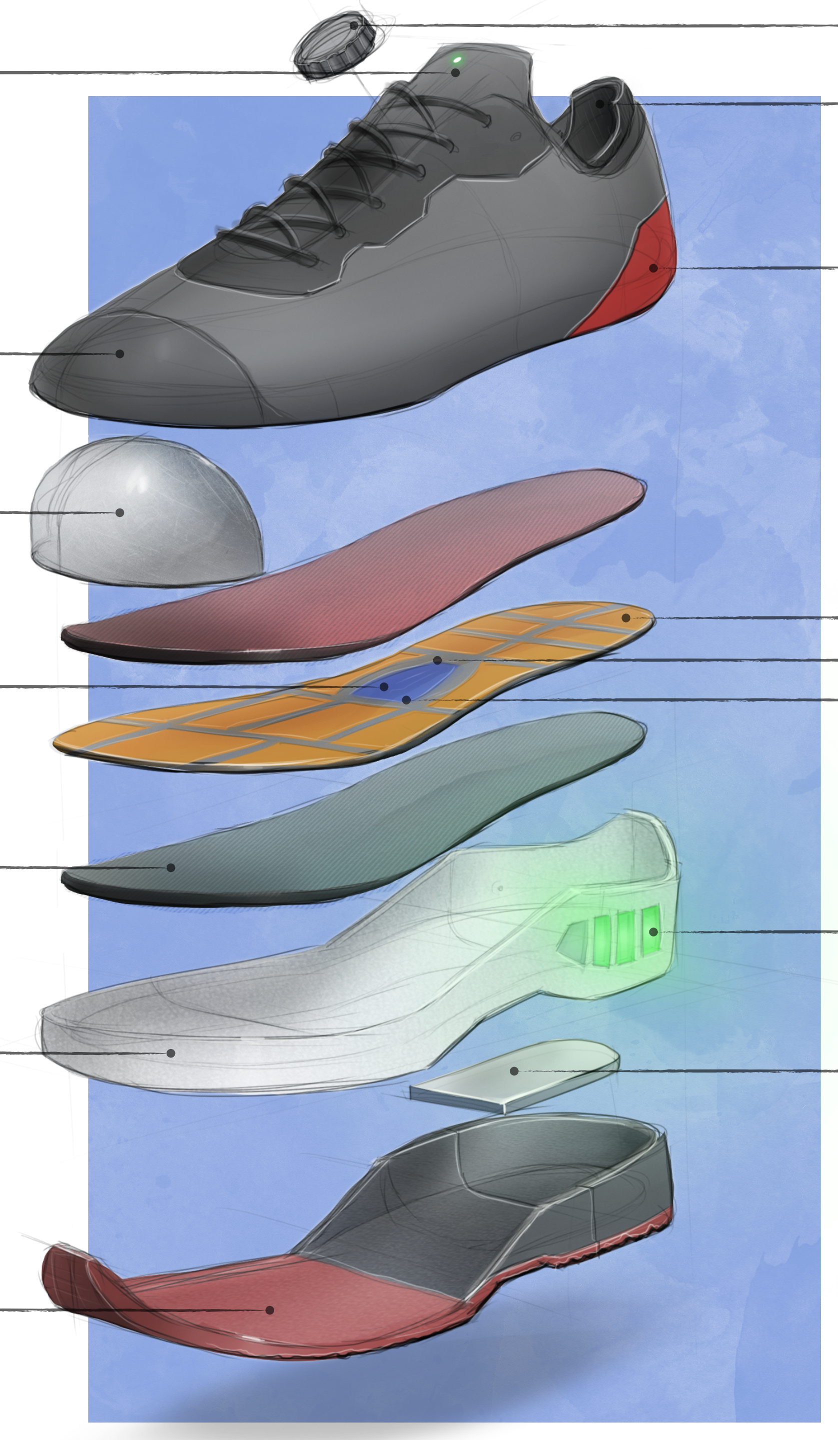


Figure 14: Exploded view of smart safety shoe

How it works - Data processing

The main capability of the smart safety shoe is to measure leading and lagging indicators of manual handling incidents. The following section will go into the method in which these insights are extracted from the hardware components mentioned in *section 3.2 smart safety shoe components*. Figure 15 presents a flowchart on how the different sensors are used to draw conclusions on leading and lagging indicators for manual handling incidents. The lines between all the different boxes are calculations that the CPU will have to make in order to get to the next output. For example, the pressure sensors measure pressure, which will have to be converted into a signal, added up to receive the sum of all the sensors and consequently translated into a weight to receive the sum of all the weight that is being exerted on the shoe. A brief indication of these calculations is given in text underneath the different boxes.

These calculation methods are a first assumption based on the research. Therefore this flowchart will need another more in-depth look and validation through testing (prototyping).

The activity states presented on the left (green colour) are useful for task classification and task-specific limitations. For example, lifting weight or pulling weight do not have the same weight limit recommendations. Furthermore, these states could be utilized for defining task frequency, shift durations and work patterns as well as smart recording of data (only recording necessary data).

The orange boxes are leading and lagging indicators for manual handling incidents. These outcomes can be utilized for feedback for manual handling incident prevention. This feedback refers to the direct feedback towards the wearer or analysis reports towards other parties. This feedback loop is discussed more elaborately in *section 3.2 How it works - Data feedback loop.*

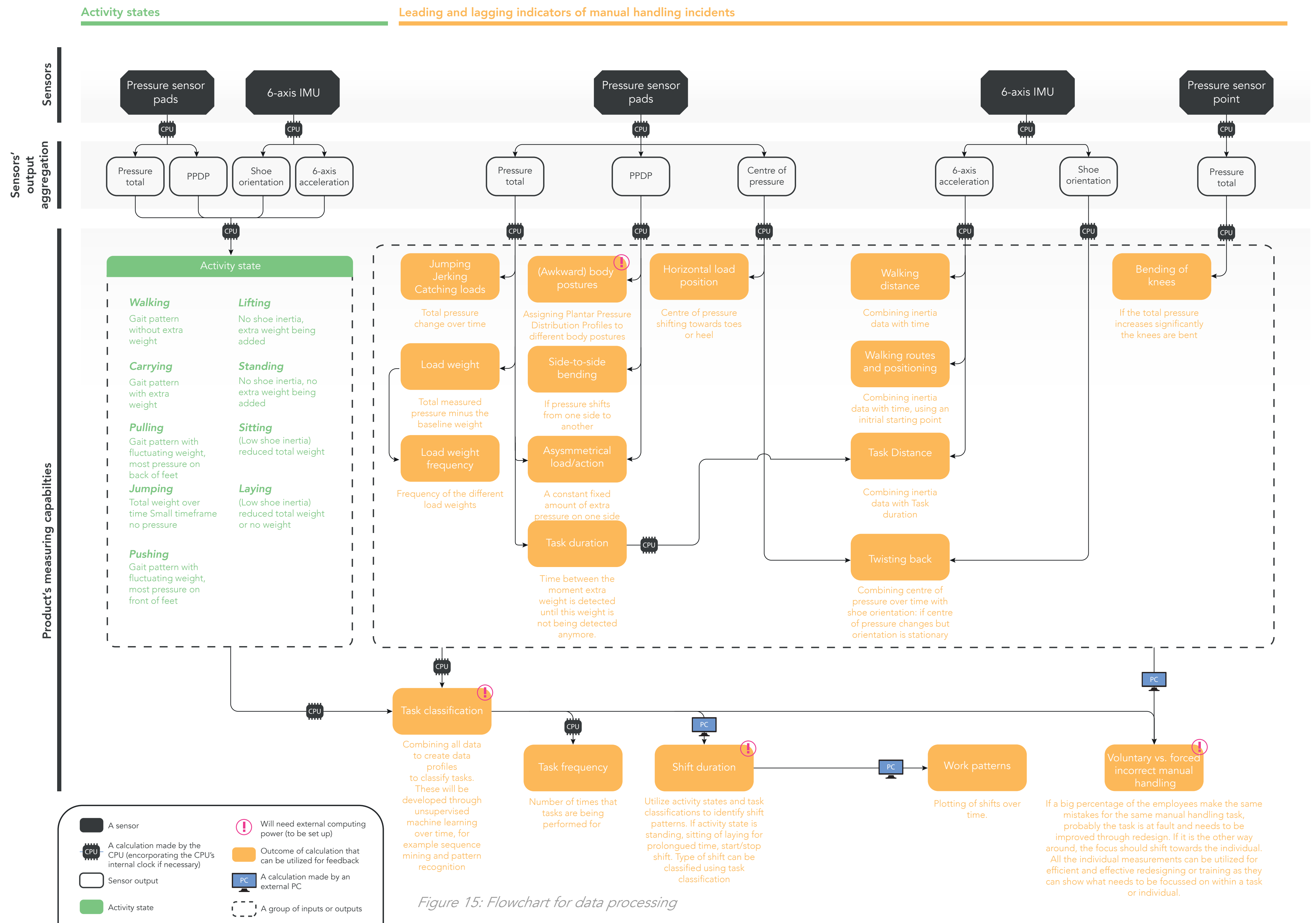


Figure 15: Flowchart for data processing

The development, of the software aspect of the shoe, is first going to be focused on setting up manual rule-based calculations (e.g. expert system or simple physics calculations) on how to get from a sensor its output to manual handling measurements (e.g. load weight and load frequency). This will be quicker and more cost-efficient compared to a machine learning approach (van der Vegte, 2020). The calculations which can not be set up in this manner will be developed using supervised machine learning (e.g. PPD profiles). Using a machine learning method (classification), a large amount of body postures can be judged and labelled by an ergonomic expert, allowing the machine to develop relations between the distribution profiles and different body postures. Subsequently, the trained model which is developed through machine learning, can then be implemented in the shoe, to be used for detection of, for example, (awkward) body postures.

Lastly, some of the calculations will be developed through unsupervised machine learning (e.g. task classification). There are two reasons why a calculation will be developed through unsupervised machine learning: 1) The outcome is not generalisable. For example manual handling tasks are not the same for each worksite and would therefore not be worth spending time, money and effort on through supervised machine learning, as the outcomes can only be deployed in that specific worksite. 2) The calculation method or outcome is unknown. Another project on unsupervised learning trained a model (through market-basket-analysis) which found a relation between pregnant women and their grocery shopping. The model was then able to identify pregnant women based on their grocery shopping and predict their future grocery shopping. This example demonstrates that through unsupervised learning, trained models can be built up to detect or even predict certain events (e.g. function or curve fitting). This concept can also be implemented in the smart safety shoe: Next to the detection of incorrect manual handling, it can possibly also predict. It can, for example, be discovered that a certain sequence of events consistently leads to incorrect manual handling technique (van der Vegte, 2020).

Not all of the calculations will have to be made within the smart safety shoe. Higher quantities of- or more complex calculations will influence the design (e.g. higher cost due to more powerful CPU or larger batteries due to more power consumption). This means that the data processing flow will have to be evaluated and optimized. All calculations that can be performed externally should be performed externally. The transfer of this data can either be done through the wireless module or a docking station (e.g. the charging station).

To add to the previous paragraph, the development of trained models through machine learning can not be performed within shoe. The processing power within the shoe is not suitable to perform calculations of this complexity. However, the trained models themselves, as mentioned previously, can be implemented within the smart safety shoe. The flowchart in figure 15, represents data processing which implements the trained models, not the development.

Models which are developed through unsupervised machine learning can, after being implemented, still train themselves with new data. Therefore, rather than having two consecutive phases (development and implementation of models), these phases can and possibly should be executed somewhat parallel after a first model is acquired. The model can continuously be trained further with new data, externally, while the first version of the model is being used within the shoe. Periodically, the model can be replaced by an improved model (which, for example, has an increased prediction performance).

The data analysis reports are created through "traditional" statistical analysis of the data processing outcomes (orange boxes). Examples of these would be what awkward posture is performed most, whether general load weight is too high, what manual handling tasks are frequently causing awkward body postures or whether incorrect manual handling is induced by the manual handling task design or the behaviour of an individual. The manner in which these insights are being implemented for the prevention of manual handling incidents is described in *section 3.2 How it works - Data feedback loop*.

Smart data collection

The more data that is being collected and analysed within the shoe, the more computing power and energy consumption is required (van der Vegte, 2020). To help with more efficient data analysis, data collection streams should also be optimized. A concept which can be implemented is smart data collection. Smart data collection means that data should not be measured and collected constantly, but only when required. For example, the total pressure being exerted on the shoe only has to be collected when additional weight is being detected and the shoe orientation only has to be measured if a manual handling task has been started.

How it works - Data feedback loop

After knowing how to measure leading and lagging indicators, the next step is knowing how to communicate these insights and to whom. Figure 16 presents the data feedback loop flowchart.

The execution of manual handling itself, if done incorrect, is considered part of the lagging indicators. The shoe can measure the execution of manual handling and provide direct feedback to the employee for reactive incident prevention. This direct feedback is located where the hazard is and is based on personal pains, which as seen in *section 2.3 Communication of feedback*, make for an effective feedback design.

Direct feedback is provided in two ways. 1) A simple LED indication on the shoes. The LED located on the top of the shoe can provide feedback on whether the manual handling task is being performed correct (green light) or incorrect (red light). The decision on feedback being provided through an LED is based on the fact that the targeted sectors have a machinery and other equipment which already induce vibration, which could interfere with the perception of a buzzer actuator for feedback. The same goes for auditory feedback, as these places can be noisy, making the auditory feedback less audible. This decision, however, still needs validation through user testing. 2) Feedback will be provided via an application (see *section 3.2 Mobile application user interface, figure 17)*. This feedback includes insights in the employee's manual handling technique, how they can improve, potential risks, etc. The goal of this feedback is to make the employee intrinsically motivated to improve their manual handling technique and transform their training into long term and frequent feedback and increase their knowledge to improve their risk assessment capabilities.

There are three main components that can influence the likelihood of an employee performing incorrect manual handling (supervision, task design and manual handling training). These are therefore leading indicators. If these three components are executed well, the chance of manual handling being performed correctly increases significantly.

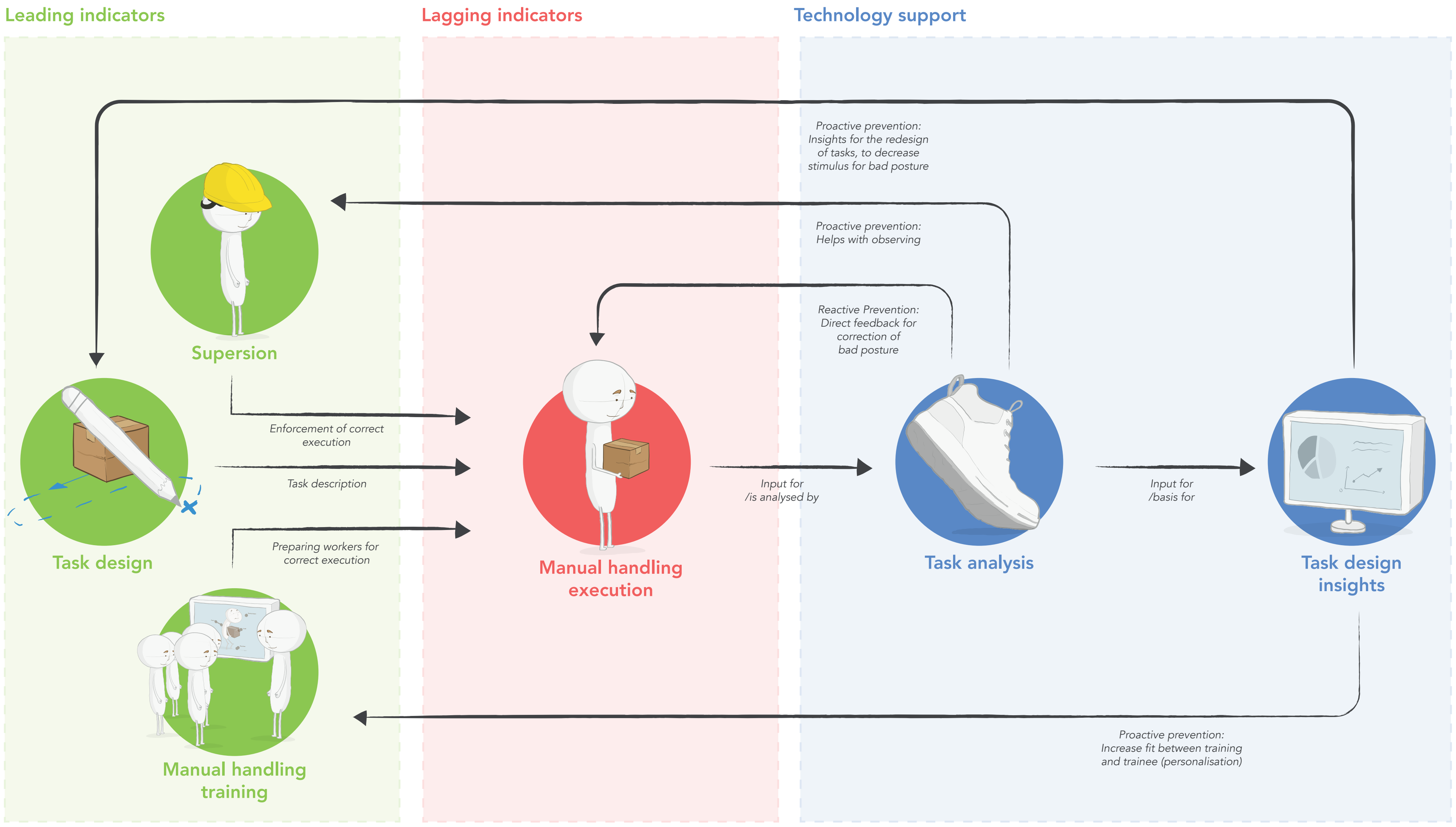


Figure 16: Flowchart for data feedback loop

The extracted data can provide feedback to the supervisor for proactive incident prevention. This can be achieved by aiding the supervisor in more accurate and effective observation, through for example warnings of incorrect manual handling streaks.

Furthermore, when the data is fed through to a more complex analysis method, patterns and trends can be derived which can be utilized for more proactive incident prevention. For example, these insights can be used to effectively redesign tasks (for example load characteristics or task frequency) or increase the fit between training and trainee (based on employee or workplace specific improvement points).

Mobile application user interface

In order to be able to provide workers with the direct feedback containing insights into the user's manual handling safety related performance, an additional interface (or application) is needed. Figure 17 shows an example of what the mobile application could look like for an employee. The application illustrates how feedback can be communicated effectively. Next to this it includes a few gamification elements which serves as a reward systems for the encouragement of safe manual handling and use of the application (which is a method for behavioural influence design, see *section 2.3 Behavioural influence design*).

Figure 17 provides an overview of the home screen and multiple detail pages is provided. The application provides an overview of the employee's safety score (based on what percentage of the lifts are executed in a safe manner) and how that score is built up from the different manual handling aspects (acts, load weight, duration and posture). This score is also displayed in comparison to the company its average, to stimulate safe manual handling through social influence, which is based on behavioural intent theory and social pressure (see *section 2.3 Behavioural mechanisms* and the towel reuse example, see *section 2.4 Smart technology in occupational safety: applications*) as well as effective feedback design (*section 2.3 Communication of feedback*). Next to this the application

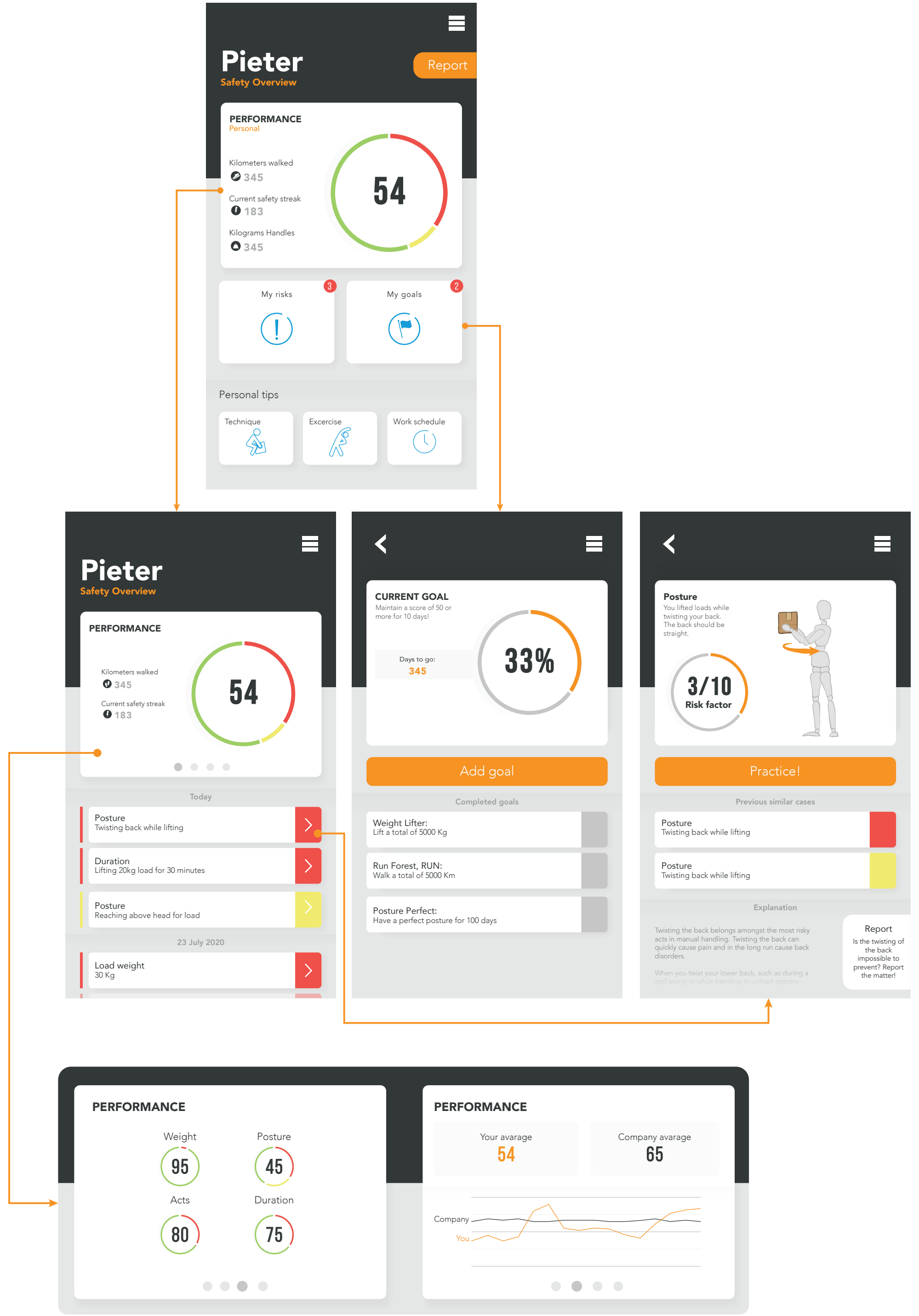


Figure 17: First mockup of a potential UI, Home screen and a few detail pages

has a list of notifications which shows insights into the exact incorrect manual handling actions that were performed, making it easy to gain the essential knowledge on what technique to correct (personalisation of risk assessment).

The application, as mentioned earlier, also implements gamification. Rewarding is a form of enforcement of desired behaviour. Statistics like "*kilometres walked*" can stimulate application-use and goal setting like "*Maintain a safety score above 50 for 10 days*" can stimulate safe manual handling (e.g. rewarding safe manual handling through digital trophies). A potential danger of a reward system, however, could be that employees do whatever it takes to get the highest score, which creates potential hazards (e.g. not taking manual handling technique into account in order to lift more weight or not taking breaks anymore).

The application also includes personal tips for techniques, exercises (which they can perform before starting a workday) and work schedules (e.g. based on their manual handling duration and weight patterns, advice can be provided to take a break). This can aid in the shortcomings of manual handling training, by providing training more frequent and in a personalised manner. The personalisation of these tips help with effective feedback as well as the presentation (animations for easy interpretation and easy to follow, see *section 2.3 Communication of feedback*).

Lastly, by going into an incidents notification, detailed knowledge is provided on the incident type and the worker can practice the movement involved. Another interesting feature would be to report the movement if the movement feels forced by the manual handling task, e.g. the task does not allow for the implementation of correct manual handling technique (this can be used for the redesign of tasks).

The user interface is not validated with users, neither is the design of all screens finalized. The illustration serves as an indication of what the possibilities are, how it can be utilized for effective feedback communication and what it could potentially look like. It needs further development and validated if the product is going to be developed.

Value map

The following section will go into the different values that the smart safety shoes are able to generate for the different stakeholders. These values are based on pains which are being relieved and gains that are being created. This method is inspired by the value proposition canvas.

The main value for workers is direct feedback on manual handling technique, which allows them to improve their technique, and increase their mental and physical health. The main value for supervisors is support and advice for managing worksites, which allows them to increase manual handling related safety, and observe more accurate and efficiently. The main value for the management of a company is insights in incident causes, and support and advice for increasing company safety, which allows for increased safety and worksite efficiency, as well as cost reduction. The main value for manual handling training providers is that they can transform their service offering into an effective one. Lastly, the product and service will provide value for insurance companies. The main value for them is that they can improve their risk assessments, and reduce costs and claims.

Figure 18: Value map for the different values that the product brings to the different parties

Business context

This subchapter will cover the viability, feasibility and desirability of the final design. It will go into how revenue is generated (through what streams, what are the (investment) costs, whether the manufacturing and methodology behind the final design are possible and whether there is a market need for it. The purpose of this subchapter is to illustrate the market potential and possibility of developing and implementing the final design.

3.3

Viability

The viability of a design is important as it ensures that an idea is able to generate value for that is providing the product and service. Therefore it is essential to know what the different revenue streams are, how much the product and service will cost and how much they can be sold for.

Revenue model

The revenue model describes the different streams of value exchange. It describes what value is being exchanged for what value, with whom. Figure 19 describes the proposed revenue model for this project its final design, which was evaluated within the company (Allshoes) and perceived as an interesting, unique, plausible and possibly promising revenue model (Arts, 2020; Riemsdijk, 2020). It represents a hybrid model of one-time-payment sales and a subscription. The following sections will go into the different value streams and how they are set up.

Smaller companies and self-employed

Smaller warehouse and construction companies or self-employed people do not need the more complex data analysis insights as the gains involved will not outweigh the costs; extracting useful trends from small quantities of employees is rare, as small changes will have a lot of influence (One employee represents for example 10% of a trend). Furthermore, if useful trends were to be extracted, the smaller companies their cost saving potential would be low(er), but they would have to pay the same for the data analysis service; for example redesigning a manual handling task would result in only a few employees who benefit from this, as opposed to bigger companies who can impact the safety of a large number of employees by redesigning one manual handling task. Corrective direct feedback on manual handling would, still interest them (Prior, 2020). As these parties only order small quantities of the product, the distribution of this product will be through a retailer. Allshoes its distribution channels are focused on the distribution of bigger quantities of a product (Arts, 2020). This retailer will receive and sell this product and in return receive a small fee for every product sold. The users of this shoe will, however, still be able to generate data that can be utilized for the creation of manual handling related macro-trends for the construction and warehousing sectors.

Bigger warehouse and construction companies

For bigger warehouse and construction companies, the product and service will be sold directly from Allshoes. The smart shoes will be sold for a fixed, one-time-payment price and separate from the data analysis service. The data analysis service will be provided to these parties for a monthly payment as a subscription. Potentially, depending on how complex the data analysis is, these parties could choose from different levels (and respective prices) of data analysis.

Manufacturers

The manufacturing of the shoe will be done by payment to the final shoe manufacturer, who will purchase the different needed materials for the production of the smart shoe. Allshoes will, however, have contact with the different suppliers, but only order products from the final shoe manufacturer. The reason for this set-up is so that the final shoe manufacturer will be responsible for the final product, allowing Allshoes to have one party to speak to when something goes wrong in the manufacturing. Otherwise Allshoes would have to go through a difficult process of deciding where the responsibilities lie each time a conflict arises.

Insurance and training companies

Two other partners in this revenue model are insurance companies and manual handling training providers. As research shows, manual handling training lacks effectiveness. Allshoes can provide insights for these training providers so that they can provide more effective manual handling training to the warehouse and construction companies. Next to this, Allshoes can boost the sales of training providers by recommending them to clients and perhaps exclusively offer this only to a few training providers. The other partner type, Insurance companies, can promote our product to the target segments which, subsequently, can reduce insurance fees for workers or companies by roughly 20% (Karelse, 2020). In return, insurance companies would have lower reimbursement costs and could use consumer data for more accurate risk assessment to predict future expenses. The role of insurance partners will still have to be explored further however, as these are yet to be validated.

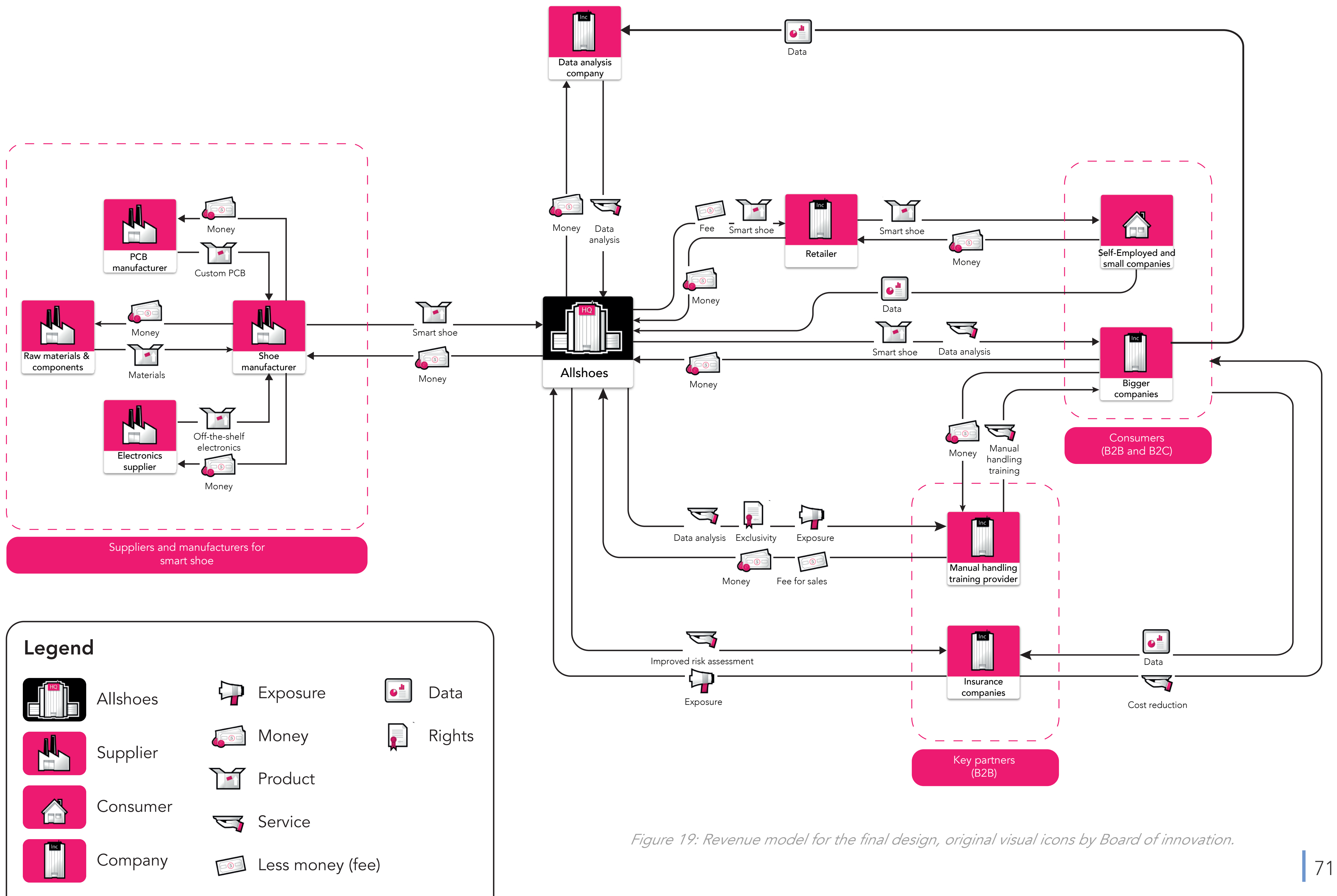


Figure 19: Revenue model for the final design, original visual icons by Board of innovation.

Data analysis company

The last player in this revenue model is a data analysis company. This company will provide a consistent analysis of the data provided by warehouse and construction companies for a monthly or annually payment by Allshoes (subscription). Allshoes can then provide the data insights from this analysis back to the companies.

Considerations and concerns

Another interesting revenue model is providing a complete service packages for the reduction of manual handling related incidents (mostly back injuries). This service would be on a monthly subscription basis that warehouse and construction companies pay for. This service would include the smart shoes (and their replacement when necessary), the data analysis service, the training and insurance reduction costs. This model is, however, too unexplored, in terms of desirability. The construction and warehousing sectors are conservative markets (Arts, 2020) and thus increases the uncertainty for the realisation of this model, too.

Lastly, not all workers in a construction or warehouse company wear the same shoes, as an increasing amount of workers are allowed to choose their own safety shoes (Arts, 2020). Therefore, the selection of these shoes might have to be incentivized (e.g. a small fees for those who use it), enforced (e.g. you can only work at a company if you use these shoes) or popularized (e.g. increase the shoes perceived desirability through advertising/presentation). This would be an exchange of goods within a company, without influence of other players in the revenue model. For this reason, this exchange will not be included in the revenue model for this product.

A main concern is the positioning of the retailers in this revenue model. The revenue model in figure 19 has no retailer between Allshoes and bigger B2B customers. The elimination of retailers is gaining popularity, as businesses are able to provide the retailer its value themselves to the consumer, which leaves a bigger profit margin (Riemsdijk, 2020). However, this setup has the potential to hurt the current relationship with the retailer as they are being excluded and potentially lose customers (and profit).

Next to this, Allshoes has a B2C logistics channel, so in theory is capable of selling directly to both the bigger and smaller companies as well as the self-employed. This means that the retailer could also potentially be eliminated entirely. Some potential models are to include the retailer in both streams and exclude them from the data, include them only in the smaller companies and self-employed stream or exclude them from both streams but perhaps provide them with a small fee for every sale nonetheless. To conclude, the role of retailers will need to be re-evaluated in the future whether they are included and in what form.

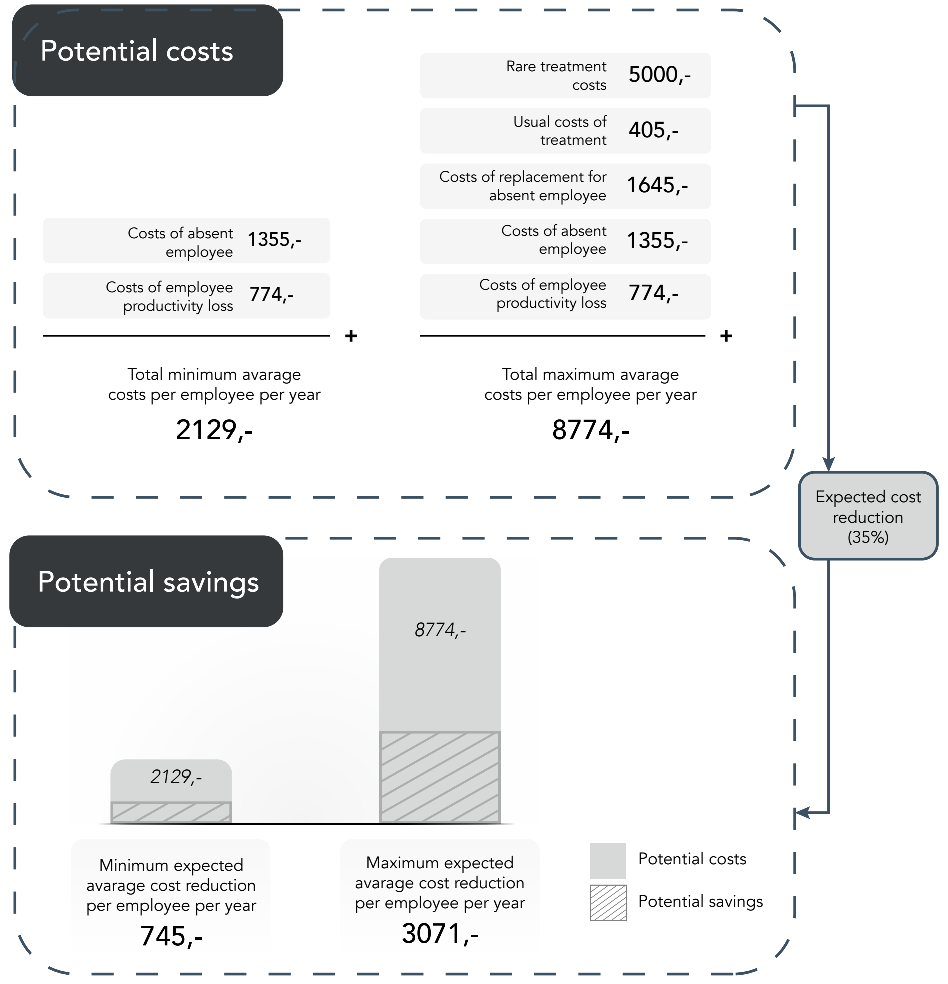


Figure 20: Avarage annual costs of backpain per employee

Estimated financial gains for customers

Manual handling related incidents, as stated in *section 1.2 Severity of the problem*, come with costs for the employer. The following section will go into the quantification of those costs by transforming the different cost aspects into absolute numbers. These numbers serve as a first rough estimation and not an exact generalisable number. This purpose of this section, however, is to present an overview of quantified value gains for potential customers, which can be used for product pricing and as a start for sale conversations (pitches). Lastly, three cost aspects are not quantified as these are not tangible enough to translate into usable numbers.

The different costs associated with manual handling related incidents (focused on back pain) are the costs of an absent employee (continued payments), costs of replacement for the absent employee(s), treatment costs, productivity loss, decreased employee well-being, lower employee retention rates and loss of company reputation. To get an idea of how much financial value the smart shoes can deliver to the customer, an estimation was made on the previously mentioned costs (see figure 20).

The costs presented in figure 20, are the average estimated costs per employee per year. The costs for one employee suffering from back pain is higher than the presented costs, as these numbers include both those who do not experience manual handling related incidents as those who do. Therefore, these costs should be multiplied by the number of employees to get the total costs of manual handling related incidents for an entire workplace or company.

Other costs involved in manual handling accidents like damaged goods or prevention program costs (H&S program, PPE, inspections, etc.) are not included in this cost overview. As it is hard to quantify the average costs for damaged goods (too heavily dependent on the workplace) and prevention program costs will not be affected through the smart shoes.

The total average costs per employee per year are estimated to be at least 2129 Euros and depending on the severity of the incident can go up to 8774 Euros. Based on the performance of a similar product (Arc, *see section 2.4 Applications*), the smart shoes are expected to result in at least a 35% reduction of these costs. A basic breakdown of this cost overview is presented in figure 20. A more elaborate breakdown of this cost overview is presented in appendix D.

Production costs of product

To get a feel for the costs of the hardware side of the shoe, a first look has been taken into the possible components. Figure 21 provides an overview of the needed components and their respective price, size and weight (per shoe). Size and weight will be relevant later in the report. A first rough estimation suggests the price of the hardware components result in a total price of 3.39 US dollars (2.86 Euros). These prices are based on ready-to-purchase, off-the-shelf components from large E-commerce platforms. However, prototyping is an incredibly important part for sensor selection; cheap sensors can result in noisy data, which makes the development of ML models considerably more difficult (Carmen, 2020). On the contrary, selecting too expensive sensors will increase the products price, which will decrease desirability. The maximum expected costs for all components in the shoe are expected to be around 100 euros. However it can be done for cheaper (Carmen, 2020).

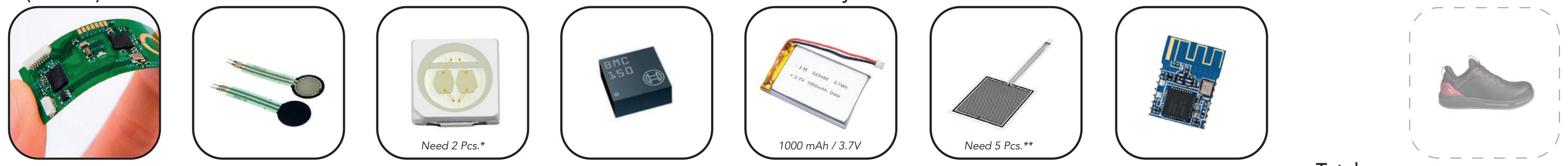
Another cost that will have to be taken into account for the production of the product are manufacturing costs. The manufacturing process of the smart safety shoe would be the same, except for the electronic components. Therefore the production costs are expected to stay somewhat the same. The main difference lies in the extra time needed for the placement of electronic components. Additional steps in the production process will bring additional costs. The current shoe is estimated to take about 20 minutes to produce (rough estimate). The placement of the electronic components is expected to lead to an increase in production time of two minutes, which would lead to an estimated 10% additional costs (Dirksen, 2020). Most of that time would be taken up by the implementation of wiring and components that need to be placed in the upper. In case the production process gets too expensive, these two aspects need to be optimized or eliminated first. The two components that are placed in the upper are a pressure sensor and an LED (see figure 14). The pressure sensor in the upper is by no means essential to the shoes their functionality (as it only measures knee bending, which can be done through more complex machine learning on plantar pressure distribution profiles) and the functionality of the LED in the upper could perhaps be replaced by the LEDs in the side of the sole.

The last type of cost that needs to be considered is the costs of prototyping. A ballpark figure for the prototyping costs of an IoT device lies around the 40 thousand US dollars mark (25 thousand Euros). This ballpark figure includes the planning and actual prototyping of the solution, but not the development of firmware and other needed software (Klubnikin, 2018). An interview with an enterprise architect of one of the market leaders in system integration provided insights in the costs and time necessary for the development of the final design. Costs are closely related to duration, therefore there are some important considerations to cover. A few considerations that were mentioned is the data privacy degree , number of operating systems it has to function on (e.g. android and IoS), frequency of data processing (real-time or batches and amount of variance in the data. Depending on these considerations, the full hardware, software and data analysis set-up will probably be around 100.000 to 300.000 Euros. The development costs from working prototype to market-ready product are estimated to be another 200.000 Euros (Croos, 2020).

Development & subscription costs of service

The entirety of service development costs for the data analysis service has already been included in the previous section on production costs for the product. However there are still some factors left to discus in terms of sercive costs.

Based on the study that discovered the relations between PPD profiles and awkward body postures (see *section 2.4 Applications*), it would require ten workers plus an ergonomic expert for a full day to collect enough data



	Custom (flexible) PCB	Force sensor	LED	6-axis IMU	Battery	Force sensor	BLE module	Total	Current shoe
Price	0.40-0.80 $	0.10 $	0.03 $	0.01 to 0.10 $	1.70 $	0.10 $	0.13 $	3.39 $	47.25 €
Size	N/A	13x13x0.2 mm	3x3x0.7 mm	3x3x0.9 mm	34x50x5 mm	42x46x0.2 mm	8.6x3.3x0.9 mm	10.5 cm3	N/A
Weight	6 g	8 g	0.2 g	0.1 g	18 g	8 g	3 g	79.5 g	510 g

**Number calculated through surface of foot/surface of sensor. based on Motion® sole, 60% coverage more than enough

*Based on design

Figure 21: Overview of needed components their weight, size and price, per shoe.

to train models for the detection of five different awkward body postures. The enterprise architect, mentioned earlier, suggested it would perhaps require 20 workers and a few ergonomic experts, for multiple days, spread across a tro month period of training time for models.

Furthermore, data specialists are around 130 Euros an hour (Carmen, 2020). This means that the data analysis outsourcing is expensive, but if optimized, managable. In order to optimize the outsourcing, it is recommended to analyse the collected data in batches, instead of real-time. Luckily this is not an issue, as the data analysis companies are involved for the identification of trends and development of ML models, which would not require data analysis on a real-time basis.

The last factor is the set-up costs of an IoT network. Carmen (2020), mentioned the cost of an IoT Network (e.g. Micorosoft IoT Hub) can be up to 2.000 Euros per worksite per month. Although, partially these costs can be shared over multiple worksites, as some of the network components do not require to be on-site for every worksite.

Cost conclusion

In total the development of the smart safety shoe and the corresponding service, will be anywhere between 300 thousand and 500 thousand. In order to launch the product more investments need to be made for the manufacturing of the shoe it self (molds, assembly, etc.), as well as the set-up of an IoT network. The setup will cost another estimated 2000 euros maintenance costs per worksite per year, which can partially be shared amongst multiple worksites.

All these investments will result in the realisation of the final design, which is also able to save a lot costs. The smart safety shoes are likely to save an avarage of 745 to 3071 Euros per employee per year (for 100 employee worksites, this would result in saving 74.500 to 307.100 euros on avarage per year.

Furthermore there are some important considerations to be made in sensor selection (price versus data noise), prototype requirements (extensiveness of prototype) and data analysis outsourcing (batch optimization).

Feasibility

In order to know whether the final design is feasible, there are some concerns we need to address: Can we fit all the technology inside a shoe? Is it possible to produce the shoe without losing the certification? Is the method we intent to implement an effective one?

Technological feasibility

The study which is presented in *section 2.4 Applications* show the possibility of identifying body postures based on PPDPs. However, to illustrate the possibility to implement the necessary technology inside a shoe, to measure the required data, a few products are presented in figures 22 up to 25. The *Motion science insole* is an insole for a shoe which holds 16 pressure sensors, a 6 axis IMU a PCB and a battery (which is almost all the technology required for the design). This product perfectly demonstrates the technological feasibility of the design: a device small enough for a shoe, which is capable of measuring plantar pressure distribution profiles in real-time, running on a CR2032 lithium ion battery (figure 26). Furthermore, to not rely solely on the products of other parties, figure 21 in *section 3.3 Production costs of product*, provides an overview

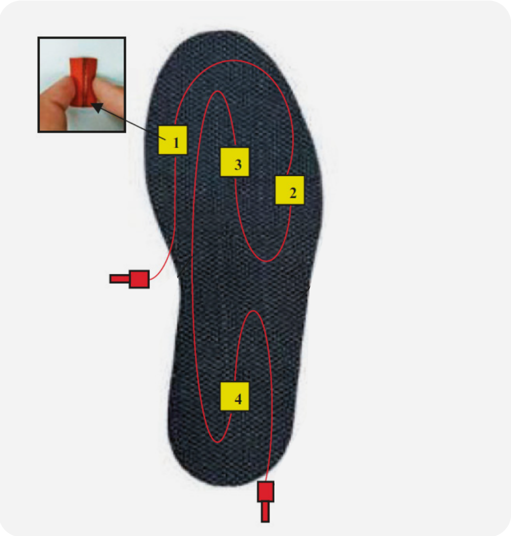


Figure 23: Smart insole

Figure 24: Sensistep

Figure 25: Gymsoles

Figure 26: CR2032 litihium ion battery (210mAh, 3.7V)

of my own findings concerning the dimensions of the different required hardware components. Considering the volume of an insole is about 120 cm^3 (30x10x0.4 cm), the technology would still fit in an insole. Therefore the required technology would definitely fit within a shoe.

Next to this, products like the SensiStep (Leihitu, 2017) (figure 24), Gymsoles (Elvitigala, et al, 2019) (figure 25) and smart insoles (Lakho, Yi-Fan, Jin-Hua, Cheng-Yu, Abro, 2019) (figure 23), which are all shoes capable of measuring plantar pressure distributions wirelessly within shoes and provide feedback on body posture, add to the believability of the technological feasibility.

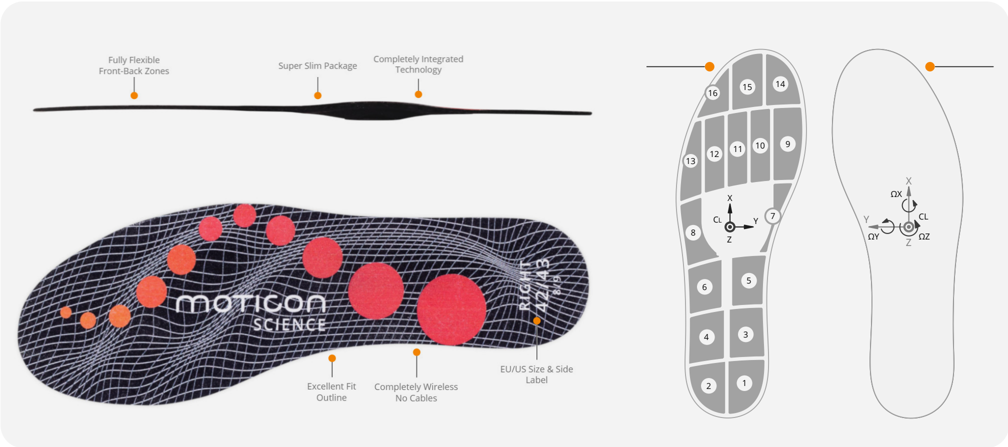


Figure 22: Motion science insole

Manufacturing feasibility

To illustrate the possibility of producing the shoe without losing certification, figure 27 provides an overview of the different concerns for different areas of the shoe that need to be taken into account. The red areas are areas which should not be utilized for the placement of components, as it can quite quickly result in safety quality certification issues. The orange areas are areas which should be avoided if possible as these are likely to be bent when in use. This causes wear and displacement of components as well as undesired stiffness in the area, which is supposed to be able to bend. Lastly, the green areas are areas which have little to no difficulties for component placement as these parts are either rigid and fixed or have little influence on safety quality certification. In general, the placement of components reduces in complications the more you go to the back end and upper part of the shoe.

Component placement

The battery will be placed in the heel side of the sole. This part is the most rugged and stiff place of the shoe, where there also is space for the battery to be placed. Furthermore, this location within the shoe will cause no walking discomfort. Placing the battery in the waist area will cause undesired stiffness and the sole is too thin for it to be placed within the sole.

The placement of the PCB (with the 6-axis IMU and the wireless model on it) and the force sensors (for measuring the plantar pressure distribution) will be placed in the insole. The technology has to be placed flat underneath the foot and can not be placed within the anti-perforation sole as changes in this sole quickly leads to problems with safety quality certification. These components can not be placed underneath the anti-perforation sole, as that would require parts of the force sensors to be in the red areas. By incorporating these components within the insole, space would be saved, and components are held in place and protected from sharp elements by the anti-perforation sole. Lastly, as seen previously in *section 3.3 Technology feasibility*, it is known that the components fit within the sole, making this a feasible location option.

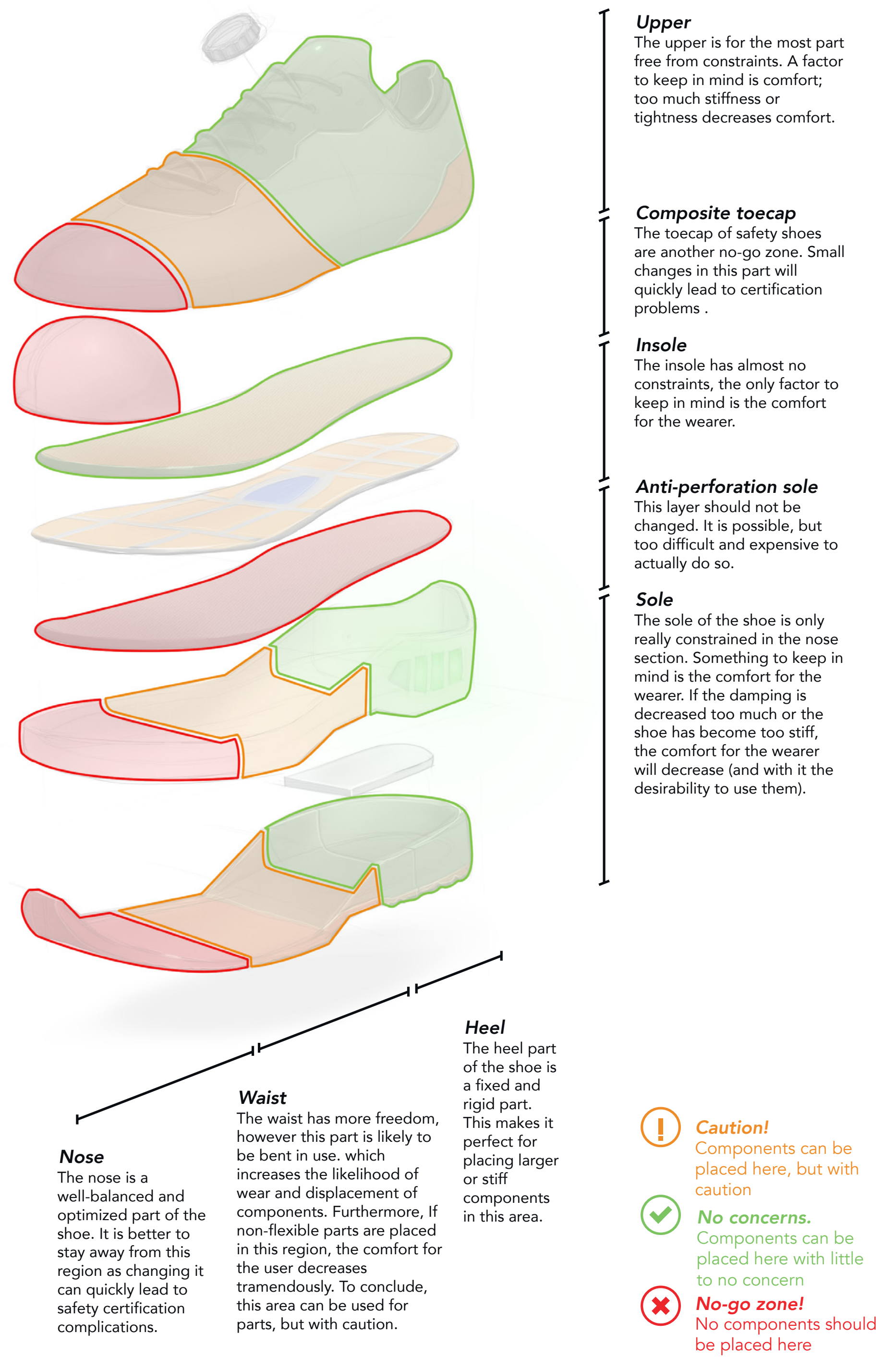


Figure 27: Concerns for component placement and production.

Placement concerns

The only concern left is the wiring from these components to the battery as these can not pass through the anti-perforation sole. However this can be solved with a bypass. With a bypass attention should be paid to the characteristics and placement of these wires: the wires should be rugged, flexible wires and located in a low-pressure, low-movement area. Somewhere between the waist and the heel should be ideal for this (Dirksen, 2020). Another option for the placement of the PCB (with the 6-axis IMU and the wireless model on it) would be near the battery. While this would not eliminate the wiring bypass, it would perhaps increase comfort as it allows for a thinner and less stiff insole.

The LEDs can be placed on multiple locations as long as they are not placed in the red areas. Preferably all the electronics and wiring, however, should not be located in the upper, as this will increase the production time and difficulty. Therefore, more exploration needs to be done on the LED location(s). On the contrary, as the current design has a force sensor, which is located in the upper part of the tongue of the shoe, the wiring through the upper would already be required. For the wiring within the upper, the same concerns apply as for the bypass in the sole and would therefore, ideally be laid between the waist and heel part of the shoe.

All in all, the manufacturing of the shoe is feasible, for an acceptable price, but requires some more research, experimentation and consideration. All these decisions and insights are based on an interview with Dirksen (2020). A first draft was made intuitively by me and consequently, independently validated by Dirksen, as he without being primed provided the same location choices, with reasoning. While Dirksen is an expert on this, he acknowledged that further research and experimentation is needed to validate the choices.

Methodology feasibility

Methodology feasibility concerns the likelihood of the method to be an effective one. The method here refers to the implementation of smart wearables, that measure leading and lagging indicators through ML models and other data analysis, which then implements gained insights through direct feedback to the worker and analysis reports to other stakeholders.

The *Arc*, another product that is focused on the reduction of back pain due to manual handling, illustrates the method its effectiveness: A smart wearable device that measures basic manual handling based on data profiles (that were set-up through ML) and communicates the measured insights directly to the wearer. The *Arc* has resulted in a 20 to 35% reduction in back disorders (Chan, 2020).

Another part of the methodology feasibility is whether the shoe is likely to be adopted by the targeted wearer: construction and warehouse workers. As stated in *section 2.4 User acceptance of smart technology*, adoption of smart wearables is related to privacy risk, perceived usefulness, social influence and previous experience with smart wearables.

The data privacy risk will be combated through transparency (which has been shown to be effective in a similar project, the GRP). Perceived usefulness will be dealt with through personalised feedback and insights (visualising potential gains and pains, as well as personalised tips and techniques) as well as the final design its high usability (it will not require big changes in their daily routine as they are already wearing safety shoes).

Social influence can be used to our advantage, as the solution includes the use of supervisors, which can be utilized as foremen that lead the innovation adoption. Another factor that can help with social influence is the aesthetics of the design, which is part of Allshoes' unique selling point.

Lastly, the factor of previous (positive) experience with smart wearables can not be dealt with through the design. However, the fact that they are already wearing safety shoes and that the final design is not additional wearable, as it integrates within their current PPE, could potentially eliminate this issue.

To add to the usability of the product, recharging of the shoe should be as easy and "autonomously" as possible. Fiddling with a wire does not fit in that scenario. Therefore, wireless charging would be more suitable. An even more ideal situation would be to implement smart materials that generate electricity on-the-go. However, this technology is in a too early development stage to be considered for the current smart safety shoe design (see *section 3.1 Programme of requirements*).

Another issue for adoption could be compliance rates. Lower compliance PPE, like protective goggles have a non-compliance rate of around 17%, which helps protect workers from potentially losing sight. This raises some serious doubts for the compliance rates for additional wearables that are additional to the workers their daily materials. Luckily, safety shoes are part of high compliance PPE (96% or more) as stated in *section 1.1 Introduction*.

A last factor that plays a role in adoption according to a study performed by Bouma (2020), is the goal of technological innovation. According to the study, workers want technological innovation which does not empower them to do more (heavier) work, but innovation which takes away the work in the first place. The smart safety shoes focuses on leading indicators, which reduces the possibility of workers performing incorrect manual handling technique and provide reactive feedback in case incorrect manual handling technique occurs. This method is in line with the vision provided by the construction workers included in the study.

Desirability

Apart from whether the design is feasibly and viable, it needs to be desirable. There needs to be a market need for the product. In order to know whether the design is desirable, the design will have to be validated with end users and clients. The following section will cover these topics.

User & client validation

There should be an interest from both the end-user (workers who will wear the smart safety shoe) and H&S managers or company executives. End-users are important because if they are not willing to adopt the shoe, the whole usability of the product is lost. The theoretical side of user acceptance likelihood was already discussed in *section 3.3 methodology feasibility*. However, the practical side (interviews and surveys) are an important second part. H&S managers are important as they play a role in the selection of safety shoes.

End-user desirability

In order to test initial validation for the end-user desirability, a survey was set up to test end-users their interest in- and need for the product. The survey (see appendix E) was sent to warehouse workers. Three warehouse employees responded of which two admitted back pain is a problem and occupation is a cause for this. Manual handling for these participants occurred either never or once. Important to note is that none of the participants mentioned that they implement their training knowledge in the majority of their manual handling tasks. Furthermore, while the participants were aware weight limits, knowledge on environment and manual handling technique lacked. Two of the participants (out of three) were enormously excited about smart safety shoes assisting in manual handling and even signed up for a potential pilot.

"I really see the added value in smart safety shoes for manual handling, especially if they alert you whenever you perform incorrect manual handling" - P

Pilot and partner desirability

To start off, Metselaar (2020), Health and safety manager of Bunzl Continental, had been selected to be part of the interviews with the CEO of the Arc product. Metselaar showed interest in the Arc and even decided to schedule a pilot. However, Metselaar mentioned that the smart safety shoes had more potential than the Arc and would perhaps be interested in a pilot when the product is ready. Metselaar oversees about 80 warehouse companies.

Next to this, an interview with Karelse (2020) shows potential for more pilot clients as well as insurance company partners. Karelse acknowledged the interest of Bidfood which has around 1500 employees and a big insurance company, CZ. The manner in which CZ might be interested in the product is yet to be determined. Karelse mentioned that a working prototype needed to be made before further negotiation can take place.

Lastly, Monis (2020), a H&S manager of "Company" (mother company of multiple large distribution centres), mentioned he was definitely interested in a pilot, but would have to re-evaluate once a working prototype was available.

End-user desirability

The validation so far seems promising but is still thin. Therefore, before bigger investments are made, further validation with the end-user as well as the company executives is recommended.

Strategy

The last subchapter of the design chapter will go into the strategic aspect of the final design. It will include sustainability, the roadmap and the vision statement. The purpose of this subchapter is to illustrate the strategic value of this final design and showcase the strategic potential its has for future exploration.

3.4

Strategy

The next section will go into the strategy, which is build around the final design. It will cover the sustainability of the final design as well as the roadmap for product development, including a more in-depth section on each horizon, and the vision statement that corresponds to the project.

Sustainability

Strategical attractiveness in terms of viability includes the sustainability of the revenue model (*see section 3.3 Revenue model*). Safety shoes last for around seven to twelve months (Arts, 2020). By providing the data analysis as a service from which the shoes are an essential part, the shoes are likely to be bought again when they need replacement. This together with the service itself on a subscription basis, should generate a sustained and somewhat stable revenue stream.

Part of the sustainability concerns how hard it is to copy the design (threat of new entry in the market). If competitors were to successfully enter the same market, the revenue model would be harder to sustain. Luckily there are a few aspects in the strategy which reduce the likelihood of new entries and increases the chance of a sustainable competitive advantage. First of all, in the prototyping phase, the PPD profiles will already be developed. This serves as a first "step ahead". The PPD profiles are not public knowledge and will cost time, money, effort and knowledge from competitors to acquire or develop. Second, a key partner (manual handling training provider) is established which differentiate our offering from new entries; we offer an effective training partner (unless competition acquires training providers as partners too). Third, the longer it takes for new parties to enter the market, the more knowledge (data) Allshoes will already have collected on manual handling safety. This allows Allshoes to have a more effective product and service, and be the "trustful choice". In case a party wishes to enter the same market, they would need to invest a large sum in order to be able to manufacture and distribute shoes in the first place (this factor only concerns non-shoe-manufacturers). As this first phase is crucial to the creation of a sustainable competitive advantage, an embargo on this thesis is recommended for the company, to be able to get ahead of the market in terms of development.

Competitors

As seen throughout the thesis, there are already other products developed which could be or are being used for increasing manual handling safety. The following section will go into the reason why it is still strategically attractive to develop the smart safety shoes.

The most important product is the Arc, as it is also a serious competitor. While the Arc focuses on the exact same problem as this thesis its final design and it is showing promising results, it does have some significant weaknesses. The first weakness is that it is only utilizing reactive incident prevention as it is focusing on measuring the lagging indicators of manual handling: manual handling technique. By improving a persons manual handling technique, the source of the problem is not eliminated. Furthermore, from all the lagging indicators, the Arc is only capable of measuring four indicators. Lastly, the Arc is a product which is clipped onto the back of a shirt. As this is an extra step in the workers daily routine and even eye protection PPE has a non-compliance rate of 17%, it is likely that the Arc will be facing serious non-compliance issues.

Another product is the Motion science insole. There is one obvious reason why this product is not a competitor for the targeted market segments: it costs 1.500 euros for a pair. This is simply too expensive for the target segment, which is probably also why the Motion science insole is targeted at different markets.

Furthermore, there are other products like the Smart insoles or the Gymsoles. However, these products are still in very early development and are currently not targeted at construction and warehousing (they are targeted at athletes).

Lastly, other potential competitors that could be considered are manual handling training & courses providers, but as seen in *section 2.2 Training*, these lack effectiveness and our product tried to support those services, not compete with them.

Roadmap

Now that the final design is decided upon and the strategic attractiveness is addressed, the question that remains is how to get there. For this a roadmap is created, which maps out the development path of the smart safety shoes and illustrates strategic potential. The roadmap is divided into three horizons.

The first horizon focuses on the development of a prototype. The goal of this horizon is to have a working prototype which can be used for pilot testing. The capabilities of the shoes are still minimal and are solely focused on the detection of lagging indicators of manual handling technique. Key activities, therefore, are prototyping of hardware and software and acquiring pilot testing clients.

The second Horizon focuses on the development of the first marketable version of the smart safety shoes and setting up the revenue model. The goal of this horizon is to launch that first version. Key activities for the second horizon are mostly focused on acquiring partners, developing the product and setting up machine learning data analysis models for the detection of leading and lagging indicators of manual handling related incidents.

The third horizon expands on the second horizon by adding prediction models to the data analysis service, which is the last step in completing the service. Next to this, the third horizon is meant for market (segment) expansion. Market expansion concerns the selling of the product in other regions within Europe or adjusting the product for other market segments. Next to this, the product portfolio could be expanded. Assuming the smart safety shoe has been adopted within the market segments, it can serve as a fundamental basis for product portfolio expansion. Developing sensors for manual handling tools, combining the data analysis with existing warehouse management tools and general data (e.g. weather) will lead to true ubiquitous manual handling safety.

The main role of Allshoes in this roadmap is to be "captain" of the ship. They acquire or hire partners with the capabilities to execute the needed steps presented in the roadmap, and thereafter manage and lead these partners accordingly. They currently have a similar approach for own (core) business. A lot of their work is outsourced, but they have in house experts on the different capabilities who lead the outsourced work. Therefore, this approach is a suitable one for Allshoes to implement.

Vision and strategy

All the steps in the roadmap lead to a certain outcome, the vision statement. The vision statement is a desired future scenario. It serves as a strategic guideline for the development of the smart shoe direction. For this project, the vision statement is:

"Allshoes provides smart ubiquitous safety for manual handling related risks in construction and warehousing worksites"

Ubiquitous safety means that every single potentially hazardous factor is being considered, all of the time, and safety is present everywhere. To make this an achievable goal, the ambitious safety characteristic is scoped down to manual handling related incidents and only for construction and warehousing sectors.

As previously mentioned, the solving of manual handling related incidents is a well-suited task for smart safety shoes, which makes it an well-suited and promising direction for Allshoes, market leader in safety shoes in the Netherlands, to follow.

The fourth horizon

Following up on the main vision, once the third horizon is reached, the vision could potentially be expanded to a more general meaning:

"Allshoes provides smart ubiquitous safety for worksites"

While this is an even more ambitious vision statement, it allows Allshoes to build upon the already established smart safety shoe for manual handling and use it as a basis to expand to other regions of safety. An example for this would be to set up an IoT network (or SNS) to create smart environments, which take all hazardous risks into account, all the time.

The fourth horizon is focused, therefore, on further exploration of the vision. The goal of this horizon is to try and set up a service system offering smart ubiquitous safety systems for more than just manual handling related risks.

ROADMAP

Product development
and strategic potential

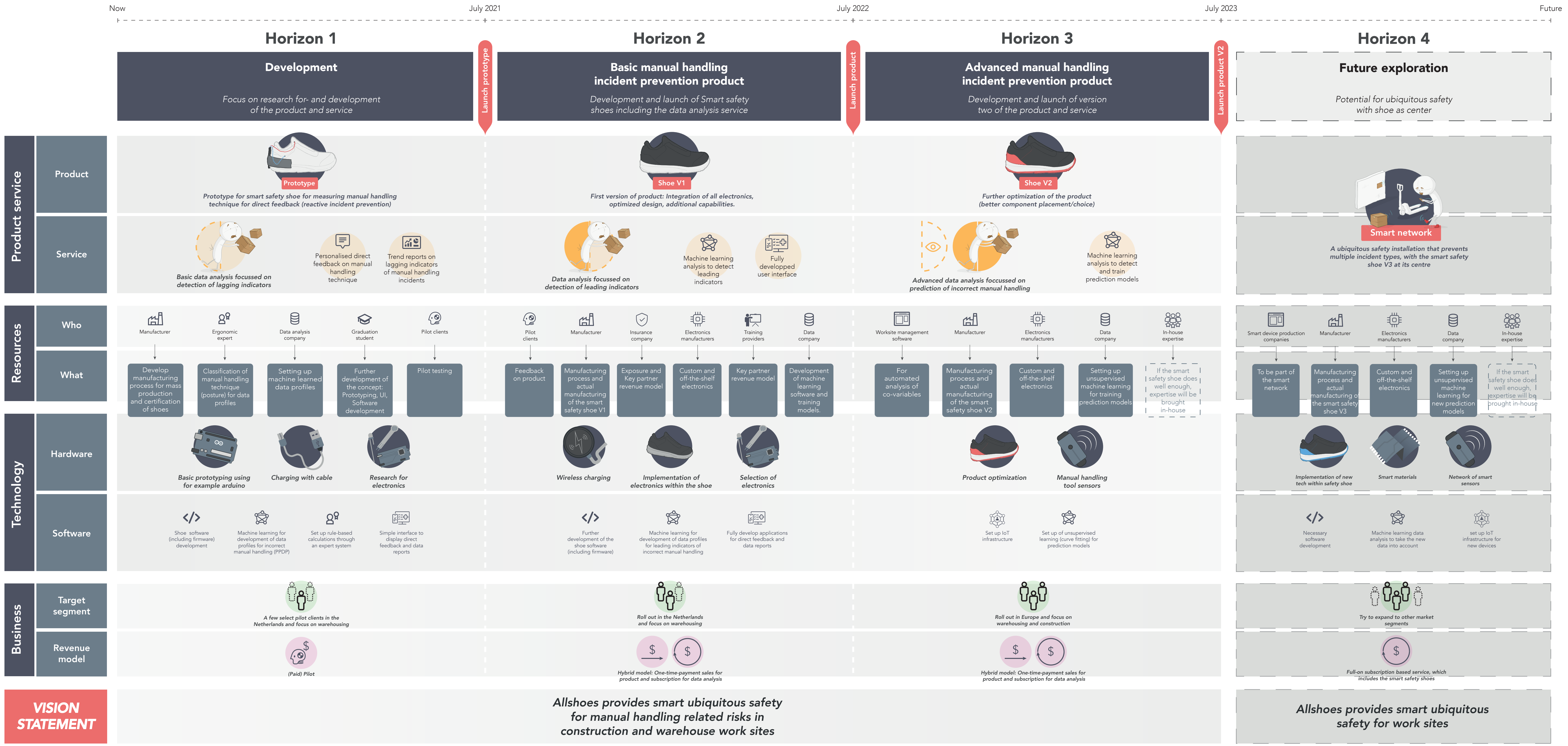


Figure 28: Roadmap for Allshoes, built around the product

Horizon 1 - Realization

Product and service

The goal of this horizon is to have a working prototype for the smart safety shoe that is capable of measuring and assessing basic manual handling and provide basic feedback. This means that it is able to detect: 1) Bending of the torso, both forward (extension and flexion) and side to side (lateral). 2) Twisting of the torso (axial, relative to the hip). 3) Simplified task duration and task frequency. 4) Weight of the load being handled. 5) Detection of unsafe manual handling acts (jerking weights, jumping and catching falling loads).

The first data analysis reports, will be done using more traditional analysis methods. Outcomes of this analysis will be relatively simple, but useful, insights like: Common incorrect manual handling (e.g. undesired postures), and peeking hours of incorrect manual handling.

Technology

This prototype will be made through standard components with easy modification possibilities (for example Arduino). This allows for fast prototyping and early testing. The first exploration and elaboration steps of this horizon will be done in collaboration with the TUDelft, with a master student IPD. The reason for this is to further investigate and develop the technological (including sensor research) and data analysis aspects of the project without spending too much resources (money and effort) on it.

It is important that a first promising prototype is made promptly, so that the data collection can be initiated. Based on this data collection the first steps can be made in the development of data profiles for incorrect manual handling (plantar pressure distribution profiles). These profiles are set up through simple rule-based calculations (expert system) and supervised machine learning (classification). In

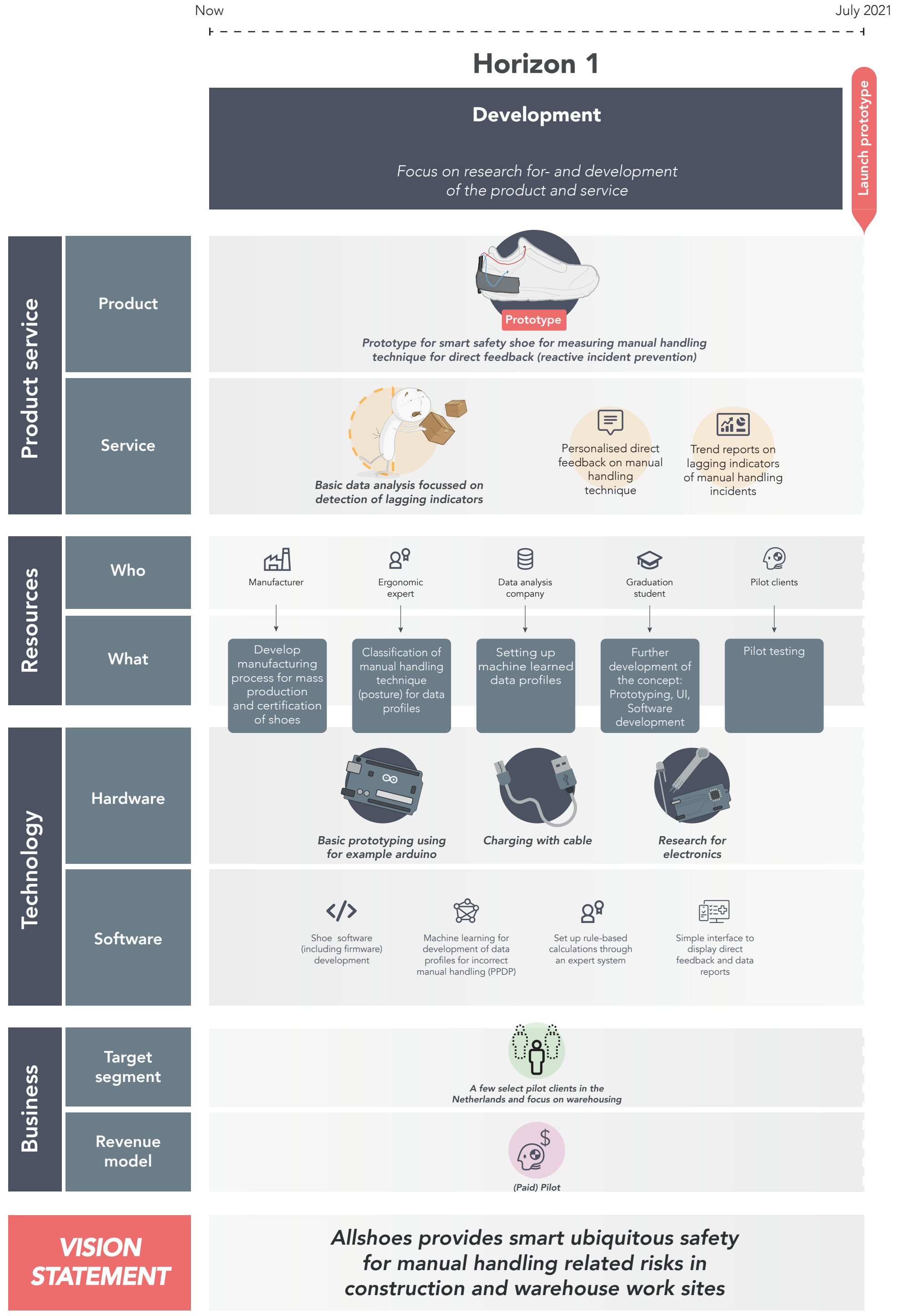


Figure 29: Horizon 1 of the roadmap

order to do this, an expert on the ergonomics of manual handling will need to be brought in (hired) and a data analysis partner will have to be selected (as well as around 10 to 20 workers to perform the different manual handling tasks). A consideration to be made here is to use an already existing insole (e.g. the Motion science insole, see figure 22), which would allow for development of ML models sooner in the development phase. The advantage of this is a more rapid development process, thus achieving a head-start on the competition more rapidly.

In order to have a functioning prototype, a first version of the smart safety shoe its software will have to be developed. An rough user interface for feedback and display of data will have to be developed (which will be outsourced) alongside the system its software (including firmware). This interface can be basic as well, as there is no elaborate data feedback required in this horizon. This user interface will only require the display of direct manual handling feedback (what correct or incorrect manual handling is being performed) and a score for risk exposure based on the amount of safe manual handling compared to unsafe manual handling. For workers this will be in a personal manner and for a supervisor in a more general manner.

Resources & Business

As the second horizon will start with pilot testing, a pilot client will have to be selected. In *section 3.3 User & client validation*, some potential pilot clients have already been proposed. For the selection of these pilot clients there is a focus on warehousing. As mentioned in *section 2.1 General causes*, warehousing worksites have more stable conditions, which make pilot implementation more simplistic, which is perfect for pilot testing and a working prototype. In this phase, no revenue is generated other than perhaps some early pilot payments.

Some of the other resources have already been discussed, like the ergonomic experts, the graduation student and data analysis company. However there is still one more to discuss: the shoe manufacturer. It is important that the shoe manufacturer is already involved in the process in the first horizon as this prevents the need for delays due to knowledge transfer and complications with the production process. In addition to this, the manufacturer can provide valuable information for the prototyping phase too.

Time frame

The total assigned time frame for this horizon is ten months. Six of these months will be spent on the follow-up graduation project with the IPD master student. The remaining four months will be spent on the development of a working prototype and development of the first data analysis steps in preparation for pilot testing. The development of ML models of this calibre is estimated to take around two to three months (Carmen, 2020).

Horizon 2 - Optimization

Product and service

The goal of this horizon is to launch the first version of the final design for the smart safety shoe. This version has all electronics integrated within the shoe and is capable of a more elaborate data analysis which is mainly the addition of leading indicator detection. These capabilities will add on the prototype its capabilities, with the following: 1) Task classification and task characteristics. 2) Shift duration and work schedules. 3) Walking routes and positioning.

Resources

This horizon will start with the initialization of pilots at worksites in order to test the working prototype, gain feedback for iteration and further build up the database to develop data profiles for incorrect manual handling detection. Another value gained from these pilots are cases which help prove the product its worth to (larger) future clients.

Next to this, once of the main activities for this horizon is acquiring the necessary key partners:

1) Manufacturers for customized electronics (e.g. PCB) and some suppliers for off-the-shelf components (e.g. IMU and CPU).
2) A company capable of performing the data analysis and setting up ML data analysis models for the detection of leading and lagging indicators of manual handling related incidents. It would be wise to have the same company as in horizon one, for knowledge transfer reasons.
3) To complete the revenue model two key partners that need to be selected are an insurance company and a manual handling training provider. For the insurance partner, a suggestion has been given in *section 3.3 User & client validation*, a training provider will still have to be searched for.

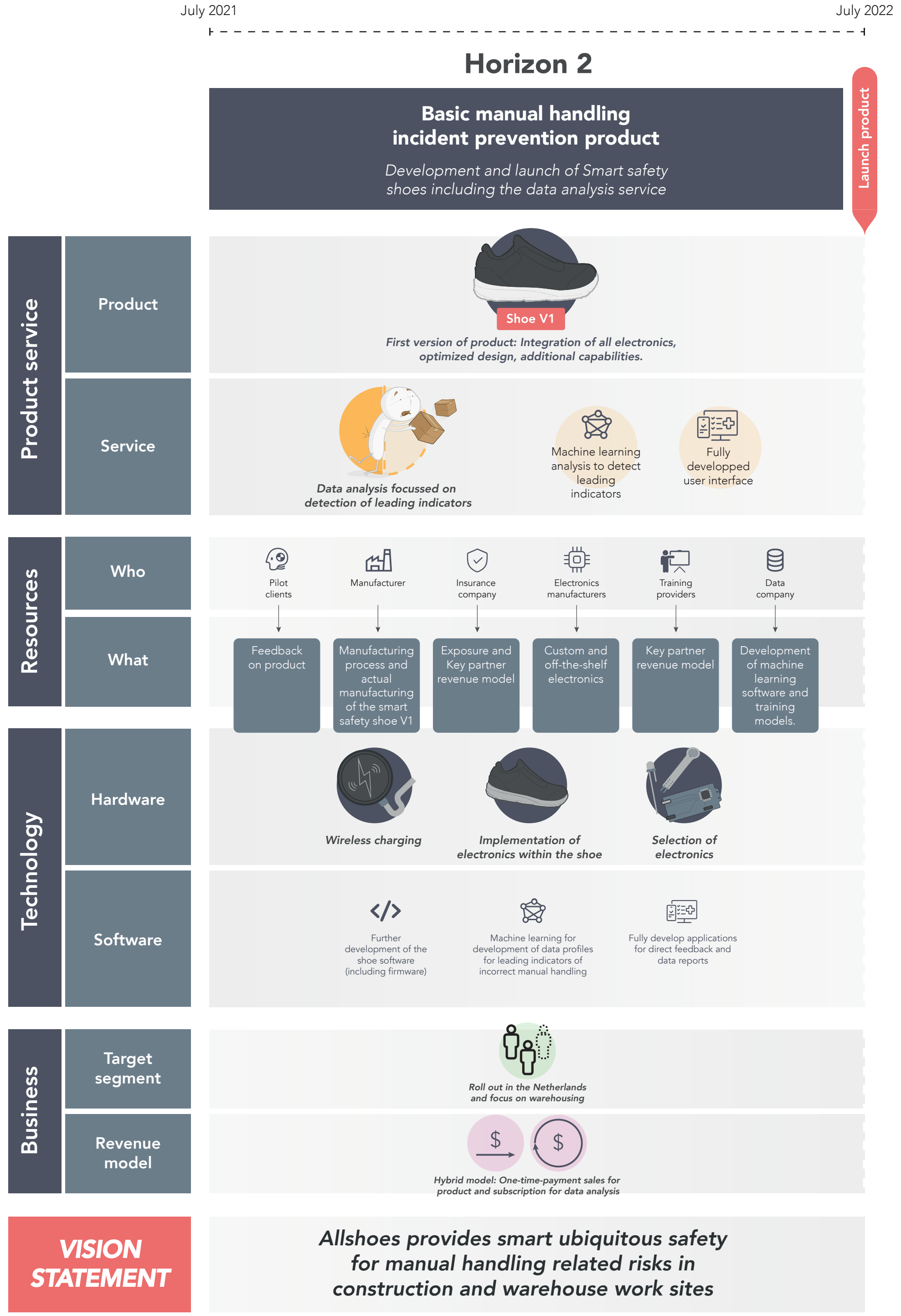


Figure 30: Horizon 2 of the roadmap

4) Possibly, there will be a need for a new shoe manufacturer, in case the current manufacturer is not capable of altering the shoe design for the incorporation of technology. It would be wise to already have a manufacturer on board in the first horizon so that the manufacturer is already up to date for when the first product batch needs to be produced, as explained in horizon one.

Technology

Software and hardware advances will have to be made. The user interface will have to be updated to be able to display the new data and be aesthetically pleasing as well as intuitive for the users. The application will also include some first features for goal setting, to incorporate a reward system (gamification) and methods for behavioural change. Next to this, the system its software (including firmware) will have to be updated to incorporate the new hardware changes. Hardware-wise, proper sensors will have to be selected and some (for example PCB) will have be custom developed. In horizon one, the IPD master student should have done the initial research for this. Lastly, a final design will have to be developed for the final aesthetics and incorporation of electronics within the shoe.

Business

In horizon two, as the official pilots are initialized, a small amount of revenue is generated through payments for the pilots. The main revenue streams described in the revenue model (*section 3.3 Revenue model*) are being set up in this phase and will, therefore, only start to generate revenue once horizon three starts. Furthermore, first version of the product is going to be launched at the end of horizon two, which will be targeted at the warehousing sector throughout the Netherlands. Construction is still not being considered in this phase for the same reasons as in horizon one.

Time frame

Once the pilots are finished and feedback is incorporated, technological advancements are made, key partners are selected to wrap up the revenue model set up, and the manufacturing process is altered, the first version of the final design is ready for launch. In order to be able to launch the smart safety shoe, the shoe will have to be certified (qualified safe by certain safety standards).

The time frame of this horizon is one year. This time frame is based on the current product development cycle of Allshoes, which is one year (Arts, 2020). As everything will be outsourced, and all the new technology is available already for mass production, the additional tasks that are being outsourced should not necessarily result in a longer development route.

Horizon 3 - Elaboration

Product and service

The goal of the third horizon is to have a second, upgraded, version of the product and service which is ready for market and implements more advanced analysis: prediction. These updated capabilities include: 1) Comparison analysis to identify co-variables. 2) Manual handling tools related risks analysis (e.g. tool specific load weight limitations). 3) Unsupervised machine learning to train prediction models for both leading and lagging indicators.

The automated comparison analysis focuses on general environmental data, as well as worksite-specific data. This allows for the identification of leading indicators like weather, load type, time, projects and work schedules. These databases, together with the data from the smart safety shoes, will be utilized for unsupervised machine learning to train prediction models (e.g. curve fitting or pattern recognition). This is the last step in the data analysis service, which adds the prediction of leading and lagging indicators to the already existing detection (which was set up in the previous horizons).

Technology

Technological advancements for advanced manual handling analysis include the development of tool sensors to include tool load weight limits, tool use and end-of-life analysis. Tool sensors can be as simple as RFID tag technology, which only indicate a certain tool is being used while the shoe does the required calculations.

Next to this, software needs to be written for the sensors as well as any updates in the shoe. Also ML prediction models need to be set up. Lastly, in case the tool-specific sensors are implemented, also the IoT network needs to be reconfigured.

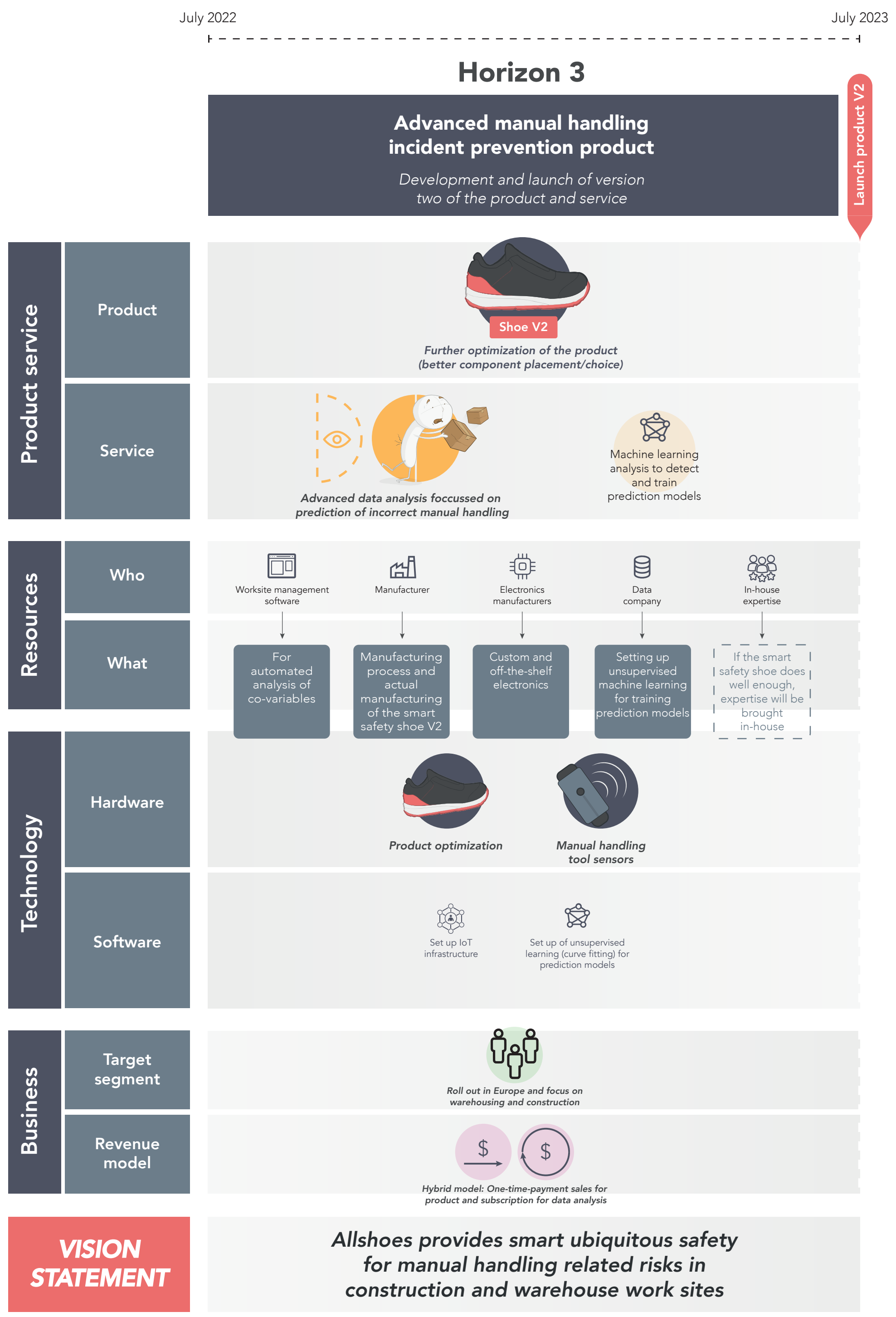


Figure 31: Horizon 3 of the roadmap

Resources

Potentially a collaboration with worksite management software companies can be set up for the comparison analysis features mentioned previously. This would allow for a more autonomous process. Other resource partners in this horizon are the same as in the previous as these are maintained.

In this horizon, in case the sales for the smart safety shoe are high enough to become one of Allshoes its main revenue streams, expertise will be brought in-house. This will be done in the same matter as explained in *section 3.4 Roadmap, where a "captain" of a certain expertise or capability manages and leads what is being outsourced.*

Business

Horizon two ended with the launch of the first version of the product, throughout the Netherlands. In this horizon, the product its reach can be expanded to other regions in Europe. For this, Bunzl its network can be utilized for reach within Europe. Furthermore, the revenue model will not change compared to the end of the second horizon. According to Arts (2020) the targeted market segments are conservative. Therefore, the full-on switch to a subscription model will not take place in this horizon. The market can slowly get used to the hybrid model, which serves as a stepping stone for the inclusion of the smart safety shoes themselves in full-on subscription service.

In horizon three it would also be time to start exploring possibilities for different market segments. The first on the list is construction, the other main target segment. Now that two years of development on smart safety shoes and ML models has passed, the switch can be made to a less stable worksite.

Time frame

The time frame determination for this horizon is built up in the same way as the time frame of horizon two: Allshoes' product development cycle is around a year and the technology should not have to extend this (Arts, 2020). There is however one difference. In case the product generates enough revenue for this product to become one of the main revenue streams for Allshoes, they will bring in-house expertise on relevant topics (data analytics, electronics and manual handling ergonomics) (Arts, 2020).

Horizon 4 - Exploration

Product an service

The fourth horizon still contains uncertainty, but a lot of potential nonetheless. It is focused on further exploration of the product its direction: Ubiquitous occupational safety, with shoes at its centre. This means the product could be improved upon with sensing capabilities that extend further than just manual handling, or the product portfolio is expanded upon (perhaps in collaboration with other companies) to offer a service package of ubiquitous safety for certain incident types.

Examples of these expansions could be to implement feet disorder detection based on gait analysis or provide a sensor package to detect hazardous environmental elements (gasses) which can alarm the shoe wearers. Other examples would be proximity sensors for collision prevention between employees and vehicles, fall detection or structural analysis of the worksite (for collapse detection). The shoes could be the centre of an IoT network (or SNS) to create smart environments. These examples are by no means validated to be strategically wise choices, but do illustrate potential.

Business

This horizon is also the time to start realizing a full-on subscription service, which includes the smart safety shoes. The service could shift the offering of selling shoes for a one time payment, to selling safety as a subscription. Furthermore, this horizon could be used to identify other potential market segments for future expansion. For example agriculture is another sector which involves manual handling (HSE, n.d.) and has high rates in back complaints (18-28 %) (Statline, 2004).

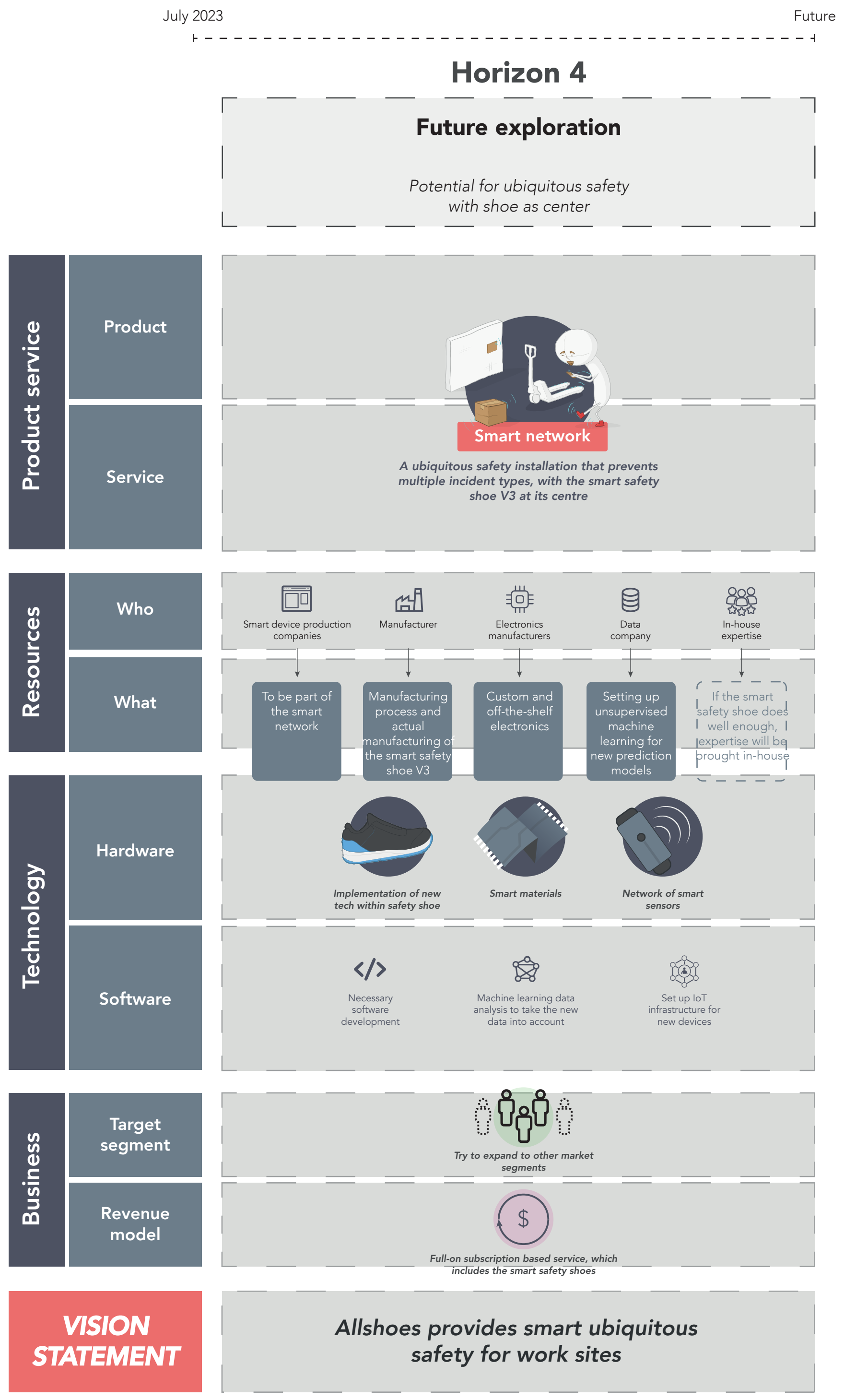


Figure 32: Horizon 4 of the roadmap

Technology

Another interesting exploration possibility is smart materials. For example the search for other power sources can be initialized in this horizon. Safety shoes normally would not have to be charged, therefore, to even further decrease the amount of adapting the employees have to do compared to their daily routine, alternative power sources could eliminate the need for periodic charging. New smart materials are capable of generating electricity by being worn (*see section 2.3 Applications)*, which would result in a continuous "wireless" charging system. This would even further increase the products usability, increasing the likelihood of adoption.

Importance of the 4th horizon

The importance of this horizon is mainly for two reasons. 1) This horizon offers more scalability by expanding on the market need it fulfils, addressing new market segments and expanding the product portfolio. Next to this the commercialization of the offering as a full-on service allows for a stable and sustained revenue stream. 2) This horizon allows for a more future proof strategy. With the trend of robotising jobs in the warehousing sectors, the need for manual handling might decrease in the far future (Ghaffary, 2019). This would essentially render the smart safety shoe useless for manual handling related incidents. As mentioned before, Warehouses are very stable environments, which makes this trend a logical progression. However, for other market segments, this transition still remains uncertain. Nonetheless, If the need for manual handling decreases and the risk become less of a problem, desirability for the smart safety shoe goes down. For this reason it is wise to work towards a smart safety shoe which offers more than just manual handling to create a strategically strong position.

Reading from the last paragraph, focusing on manual handling might not seem like a wise choice. However, manual handling related incidents are a relevant problem which includes significant costs and in the near future this problem is only likely to increase (see *section 1.2 Problem*. Therefore, the smart safety shoes serve as a first logical stepping stone to a bigger vision. For example, launching a smart safety shoe which is focused on only collision detection might seem cumbersome, as this can also be implemented in a smart watch or a smartphone. However, by having the smart shoe first focus on an incident which makes sense to implement in the shoes, we can take advantage of the present situation to increase the future potential (e.g. implement collision detection). Without focusing on manual handling first, that leap would be too big and illogical.

Conclusion

This is the final chapter of the thesis. The purpose of this chapter is to conclude and review the main section of the thesis, and reflect on the process.

4

Project conclusion

This subchapter will review and discuss the project its results. It will do so through a general project conclusion, discussing the open ends and limitations of the final design and thesis itself, and recommendations on possible future directions that can be explored.

4.1

Conclusion

The initial aim of this project was to develop a smart safety shoe of the future, which would transform the safety shoe from a passive role in safety into a proactive one. The orientation research led to a scope which focused on an incident type (manual handling related incidents), a type of technology (smart technology) and a target group (warehousing and construction). In this thesis, therefore, the main research question that is addressed is:

How can smart technology in safety shoes, in warehousing and construction, contribute in proactive incident prevention in manual handling?

To answer this question, an extensive literature review was performed (including case-based research), multiple semi-structured interviews were conducted, multiple experts were consulted, a survey was sent out to the target group and a concept was developed. All this work funnelled towards a product-lead strategy for Allshoes to implement.

Through the research, it was found that there is an opportunity for smart technology to support the current detection and prevention methods (for manual handling related incidents) in their shortcomings. There are three channels through which smart technology can support those methods, which are the individuals performing the manual handling task, the task design itself and the organization in which the individual is active. The information that needs to be communicated to those channels is the leading and lagging indicators of manual handling related incidents, which can be measured by smart technological wearables utilizing different sensors.

The paragraph above leads to the conclusion that by implementing smart technology in safety shoes, which can measure leading and lagging indicators of manual handling related incidents, feedback on the measured insights can be communicated towards the different channels. This helps to support current detection and prevention methods in their shortcomings and subsequently contribute in the proactive prevention of manual handling incidents.

The smart safety shoes have the potential of expanding into an IoT network (or SNS) when combined with other sensors and databases, which is capable of offering smart ubiquitous occupational safety. However, this requires more research into the market and the technology.

Overall, this is interesting and feasible direction for Allshoes to pursue, and creates an opportunity for Allshoes to expand beyond just safety shoes. In addition to this it allows Allshoes to expand their offering towards their main target market (warehousing and construction) even further and increase their market reach outside of their current region.

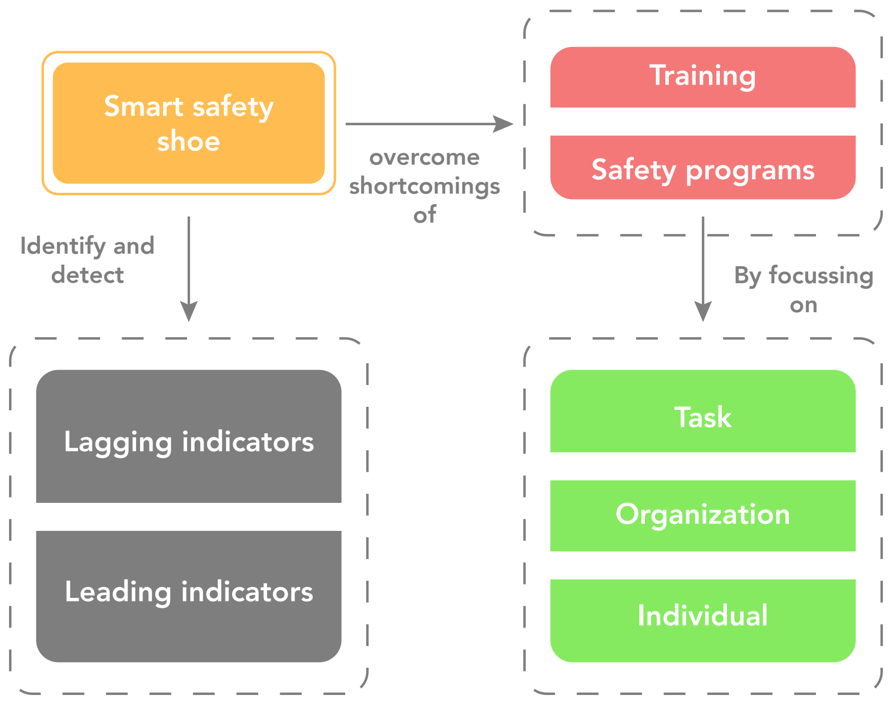


Figure 33: Thesis conclusion

Discussion & limitations

Even though the smart safety shoe concept is at a good starting position, it still needs further development (as described in the roadmap). Next to the development of the product and service itself, some further research will have to be conducted before the first version of the smart safety shoe can be launched. The considerations and limitations of the final design and its development will be discussed in the following section.

Desirability validation

Validation and development for the user interface are still in need of further research. The thesis contains a first mock-up of an interface, but is by no means validated. The different screens and feedback effectiveness of the application will have to be validated with employees. Another aspect which could use further validation is the desirability of the end-user (the wearer of the shoe). Right now, this has only been done through a survey which was sent around in a single (small) warehouse and was only answered by a limited amount of people. While this validation is not a necessary step, it helps with reassuring that the smart safety shoe will be adopted by the end-user. In addition to this, alongside exploring the desirability of the end-user, the need for incentivizing of product use could be investigated, too. Another moment for this could be the pilot studies.

The last aspect which will be needing further validation is the revenue model. The revenue model in the thesis has been discussed with the company, which acknowledged its potential. However, market validation for this setup will still be needed. It is also recommended to do market research in the possibility of future revenue models: the full-on subscription service.

Product and service

For the product and service themselves there are open ends too. First of all, the development plan needs further detailing. While the roadmap provides a rough outline of activities, it is by no means a detailed planning. Next to this the manufacturing process will have to be developed and evaluated, as this might influence sensor and actuator locations. Important factors to take into account are the production time and costs. Different considerations for the placement of components has already been discussed in *section 3.3 Manufacturing feasibility, on page 77*. As explained in that section, components in the upper will increase production time more relative to the sole. Therefore, the importance of the LED and force sensor in the upper will have to be tested whether it is crucial to have the LED on the top for it to be noticed and the force sensor to be crucial for detection of leading and lagging indicators.

Sensor selection & data processing

The electronic components still need to be selected, which will likely be done by the IPD master student. For these components the dimensions, weight, price, capabilities and power consumption will have to be considered. Another factor which needs to be taken into account is the way in which data is analysed. The higher the quantity or complexity of data analysis, the more powerful the components will need to be, the higher the power consumption will be, which will require a bigger battery or more frequent charging. By implementing data transfer in a docking station, the wireless module can be less powerful. Lastly, the factor of data noise is important for the training of ML models and utilization of trained ML models. The cheaper the sensors, the more noisy the collected data (usually). Noisy data can also be a result of sensor placement, which will need to be taken into account in the prototyping phase. As you can see, all the considerations create an interplay between the different components.

The data analysis process is another area which will need further exploration (which will be done in the graduation project of the IPD master student). The method in which the different manual handling leading and lagging indicators are being measured (flowchart presented in *section 3.2 How it works - Data feedback loop*) will need to be investigated, tested (prototyping) and validated. This also includes the considerations on how frequent certain calculations need to be made and on what device.

Furthermore, as the product requires some form of IoT network, this will need to be investigated. In this thesis a suggestion was made for Microsoft its IoT hub. Another part of this network is how data is transferred from the shoe to the external analysis device, and back. Considerations to be made are whether its wireless (which requires wireless modules in the shoe and a wireless network) or via physical ways (e.g. batches via a docking station). This decision depends on reliability, price, required feedback frequency and speed, and power consumption.

Aesthetics

The aesthetics of the smart shoe might need to be redone for the launch of the first version of the smart safety shoe. Allshoes wants to implement recent fashion trends into their shoes, which are likely to change over the next two years. To add to that, the current aesthetics of the shoe are still just a sketch and thus, need further development even if the general look is not revised.

Partners

Other activities which will need to be conducted are the selection of insurance companies and manual handling training providers. Also before the product can be launched, the role of the retailer in the revenue model needs evaluation, a patent research will need to be conducted in order to avoid legal conflicts and create the opportunity to patent the final design.

Prototype

The last points to discuss concern the prototyping phase. As explained earlier in the thesis (see *section 3.3 Production costs of product*), different considerations will drastically influence the costs and duration of the prototyping phase. The first consideration is GDRP. In case the prototype is influenced a lot by GDPR, the costs and duration will increase. Another point is the amount of operating systems that will be taken into account. If the prototype has to work on both Ios and Android, the costs and duration will increase. Furthermore, whether the data analysis for the prototype is done in batches or in real-time will influence costs and duration too. The more data analysis in real-time, the higher the costs and the longer the duration. Lastly, the UI is of importance for the costs and duration; by keeping the number of screens and the complexity of visual elements low, the costs and duration will decrease.

Another point to consider is whether the development of ML models is done with the smart safety shoes prototype or the motion science insoles. By acquiring a pair of Motion science insoles, the development can run parallel to the development of a working prototype, instead of linear.

Project scope

Initially the brief was framed in a much broader sense: Smart safety shoe to increase safety. This thesis has been scoped down to one promising direction: manual handling related incidents in construction and warehousing. However, the other directions could still be explored, potentially as part of horizon four. This also includes the targeting of other market segments and other incident types. Only general research has been conducted on other possible directions to pursue and no research has been conducted for other target segments. Therefore, in order to expand to other segments or incident types, new research will have to be conducted.

Design process

One limitation of the thesis itself is the design process (synthesis). As the research took up a lot of the projects timeframe, the divergence phase and decision making process were not as elaborate. It could be considered to revisit the design goal and explore different options in a more elaborate manner. However, the final design which was selected from the design process did gain traction and the theoretically complies with all the different requirements.

Recommendations

There are many different features that can be explored for the smart shoes. Some of these are more shoe-specific than others. For example, analysing employees their gait can show insights in feet disorder development and body imbalance. Furthermore it could potentially serve as a podiatrist that is always with you. Other possible future directions to explore which would be suitable for the smart shoes is additional unsafe acts (e.g. jumping out of vehicles is considered as a frequent hazard (Metselaar, 2020)) and end-of-life analysis for the safety shoes (e.g. after a number of hours used, the sole its profile is worn or the shoe its damping is insufficient).

Another interesting feature to explore is gesture control. This could for example be utilized for a man-down-system, which was highly desired by multiple H&S managers (Metselaar, 2020 ; Monis, 2020), or assist in reporting unsafe elements & incidents (e.g. tap the side of the shoe to report). Other directions could include social distancing sensors, collision detection or optimizing working routes.

Furthermore, the utilization of the phone sensors could be explored. This could either serve as an optimization or update step for the current final design, or as an feature expansion in a future concept of the smart safety shoes. In the current safety shoes, it might be able to either replace sensors or provide additional data for the development (other) ML models. A drawback of this is that it will drain the users their phone batteries.

Personal conclusion

The following subchapter will include a personal reflection on the thesis process and initial ambitions. The purpose of this personal reflection is to first of all evaluate and thereafter conclude my learning which I will take with me in future work.

4.2

Personal reflection

During the project I have faced quite some roadblocks. One of which was the thesis its readability. At first the report was written in a chronological order, which made it a hard to understand and follow the report. After evaluating the structure I decided to change the report to a logical order. This meant that the report became result orientated, instead of a process one. One drawback from this, however, is that I started to pay less attention to documenting the process in the second half of the project. While this is not much of a problem for the research phase, it is for the synthesis phase. In the future I will make sure to document the process every step of the way.

Another improvement point for me is planning. While I have become better at planning over the years, larger project still pose difficulties. For this project in particular, I planned weekly in general and started every day with reviewing my most important tasks. Unfortunately, I did not include the full project its general planning as much on a weekly basis. As the project planning was digital, it was easily forgotten. In the future I will try to print a physical copy of the planning which will always be present to remind me of the projects general planning.

The third point I would like to address in this reflection is the redefining of the scope. The initial project its scope was too general, aimed at only smart technology and safety. At the kick off meeting of the project, this got further defined to a target group (warehousing and construction). Later in the project, I struggled to achieve concrete results. As there were too many options to consider and evaluate, it felt like overwhelming. Because of this I reframed the scope and narrowed it down to only one type of incident which might not be the most important part of safety, but an important part of safety nonetheless. In the future I will pay more attention to the scope of a project at the beginning, to prevent time loss later down the road.

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5

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Arts, J. (2020, March 23). Videocall interview.
(Operations manager Allshoes)

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(BIM Director, Vink Bouw)

Burink, G. (2020, April 14). Phone interview.
(Safety Expert)

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(CEO, VITinitiative, Arc)

de Bruyn Kops, F. (2020, March 24). Videocall interview.
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Dhall, A. (2020, July 16) Videocall interview
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Dikken, C. (2020, June 17). Phone interview.
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Goulhout, A. (2020, April 9). E-mail interview.
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Joost Riemsdijk (2020, March 23). Videocall interview.
(Sales manager Allshoes)

Karelse, A. (2020, August 27) Phonecall interview
(Senior consultant, VLC)

Langenhuijsen, D. (2020, April 15). Phone interview.
(Market manager, Wiltec)

Leihu, C. (2020, Jun2 16). Phone interview.
(Graduation student, Sensistep)

Metselaar, J. (2020, April 8). Videocall interview.
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Philippe Cornette
(Principal, Dupont Sustainable Solutions Belgium)

Portwood, D. (2020, April 15). Videocall interview with N. Touré.
(Change Management Manager & Accountmanager Greenroad Project)

Scheele, D. (2020, April 13). E-mail interview.
(Podiatrist, MCvSA)

Sep, S. (2020, March 24). Videocall interview.
(Finance manager Allshoes)

van der Drift, J. (2020, April 20)
(Student physiotherapist)

Vandergert, N. (2020, June 17). Videocall interview.
(Head of Corporate Responsibility, Bunzl Australasia)

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(H&S manager, Company)

Carmen, S. (2020, September 28) Videocall interview
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(Enterprise architect at market leader in system integration, Company)

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Bluetooth module size and weight indication
https://eu.mouser.com/ProductDetail/Taiyo-Yuden/EYSHSNZWZ?qs=AQlKX63v8Ru66vr3hg8chw==

Battery specifications and dimensions indication
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Force sensor (Circle) weight indication
http://biosignalsplux.com/downloads/docs/datasheets/Pressure_(FSR)_Datasheet.pdf

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