Lloyd's Register Foundation

Foresight review on design for safety

Protecting lives from the start

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About the Lloyd's Register Foundation

Our vision

Our vision is to be known worldwide as a leading supporter of engineering-related research, training and education, which makes a real difference in improving the safety of the critical infrastructure on which modern society relies. In support of this, we promote scientific excellence and act as a catalyst working with others to achieve maximum impact.

The Lloyd's Register Foundation charitable mission

- To secure for the benefit of the community high technical standards of design, manufacture, construction, maintenance, operation and performance for the purpose of enhancing the safety of life and property at sea, on land and in the air.
- The advancement of public education including within the transportation industries and any other engineering and technological disciplines.

About the Lloyd's Register Foundation Report Series

The aim of this Report Series is to openly disseminate information about the work that is being supported by the Lloyd's Register Foundation. It is hoped that these reports will provide insights for the research community and also inform wider debate in society about the engineering safety-related challenges being investigated by the Foundation.

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Contents

Executive summary

This review explores how a culture of design for safety can enhance the safety of the world around us. Design for safety goes beyond legislation, regulations and standards. These all play an important role for established products and services but their limited scope often leads to missed opportunities to enhance safety by taking a broader perspective.

Design is applied to both mature industries (which have many years of experience and a good understanding of risks and how to reduce them) and emerging industries (that use new technologies requiring new ways of controlling risk which may not yet be known or understood). An example of an emerging risk is the internet that is enabling rapid innovation of new products which generate data. This data is widely shared across the internet and the risks associated with this are as yet not fully understood by the public.

A design for safety culture takes a holistic approach to understanding the influences that affect safety. Such influences are varied and take into account the broader environment within which design operates, including complex interactions, behaviour and culture. It goes beyond traditional design methods and focuses on the goal of a safer design.

Implementing design for safety requires an understanding of the challenges and the methods to address them. It needs multidisciplinary teams that bring together people with the relevant skills to understand the challenges and a collaborative approach of 'designing with' rather than the more traditional approach of 'designing for'. This can be achieved through an international diverse community that works together to identify and share best practices.

Key gaps that impede the realisation of a design for safety culture

During the preparation of this report a number of gaps were identified that impede the realisation of a design for safety culture. Addressing these gaps will create a design for safety culture that will provide significant societal benefit. The key gaps identified:

- We need to embed a better understanding of human behaviour, culture and emotional states into the design of products, services and systems.
- We need a clear set of principles and ethics to create a design for safety culture.
- We need an agreed overview of design for safety methods and practices that can be applied to current and future design for safety challenges.
- We need to share best design for safety practices in industrial, institutional and educational sectors through global networks.
- We need a design for safety practice built on education and training.
- We need to learn how to deliver new products and services that are intrinsically safer through design.

Applying a design for safety approach will not only improve existing designs but importantly develop appropriate solutions to prevent or minimise future incidents and accidents from occurring.

To start debate in the design community about growing a design for safety culture, the review proposes a preliminary definition of design for safety and a set of aspirational principles that support building a design for safety culture.

Finally, the review makes a set of recommendations to bridge the design for safety gap. The recommendations are:

Identify future design for safety challenges

There is a need to establish a design for safety research observatory capability that identifies emerging major safety issues and investigates whether new design for safety methods are required.

Develop future design for safety methods and skills

Looking forwards there is a need to establish a capability that has expertise in design for safety methods including research and experimental design activity, graduate and postgraduate educational programmes and engagement with the wider international community to learn and share experiences and best practice.

Establish a network of global excellence

To maximise the impact of these two recommendations an international network of centres of excellence should be established.

The unique input of the Foundation

There is already international interest in turning the above recommendations into reality. Before the centres of excellence can be established there is a need for preliminary activity that would provide the momentum for others to grow and maintain the first two recommendations. The Foundation is uniquely placed to support the initial stages that lead to the establishment of what will be a programme that benefits society at large.

Foreword

Design shapes our daily lives and the world around us, yet we are often unaware of its presence. There are more mobile phone devices in the world than there are people and every aspect of the phone, from the way it looks to how easy it is to use, are all designed. But design goes beyond the user experience to what is inside the phone and the services it provides, and beyond, to the global infrastructure network to which the phone is connected. Perhaps the fact that we do not think about all these facets of the design should be thought of as a measure of its success?

This review takes a broad look at the role of design through the lens of the Foundation's charitable objectives.

However, the process of designing involves elements of risk which raise questions like: will it work; will people want it; is it safe? Of all these risks, the one that concerns us directly as users is safety from harm; be this physical harm, psychological harm or any other type of harm.

This review takes a broad look at the role of design through the lens of the Foundation's charitable objectives. It identifies how design should be a holistic process that brings together multidisciplinary teams and users to create safer designs that consider all the risks, not only those which are the traditional focus. It importantly identifies that new technology brings with it new risks, some of which are yet to be identified or understood. In order to create a design for safety culture the review concludes with recommendations to build an international capability that can provide the design community with the principles, methods and tools it needs to prepare for the safety challenges of tomorrow.

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Background

This report is the eighth in a series commissioned by the Lloyd's Register Foundation. It examines how design plays an essential role in creating safe conditions for us in which to live and work – therefore creating a safer world in line with the Foundation's charitable mission.

The Lloyd's Register Foundation is a charity and owner of the 258-year old Lloyd's Register Group Limited (LR). LR is a leading global provider of engineering and technology-centric professional services to clients in a range of sectors, primarily in energy and maritime, but also in food, healthcare and manufacturing.

The Foundation is a charity with a global perspective. Reflecting this the principal investigator, Prof Paul Anderson, Dean of the RCA School of Design, co-chairs Prof Rachel Cooper and Chris Ross, and co-investigators Prof Ashley Hall and Dr Laura Ferrarello identified an international expert panel comprising of industry, academia, government, regulators and representative bodies. The panel assembled in London in February 2018 for a two-day symposium to consider the subject of design for safety from cross-sector perspectives with a second more focused event in March 2018.

The Royal College of Art (RCA) provides postgraduate education at MA, MRes and PhD level. Its intensive teaching and research environment brings unique and transformative experiences of design for many real-world, life- and safety-critical situations. Central to the success of the college is a multidisciplinary, inclusive and human-centred approach. As a global university it researches and collaborates with extensive networks in academia, industry and government. The RCA School of Design plays a pivotal role in such networks, which aims at increasing the collaboration of the RCA with STEM (science, technology, engineering and mathematics) subjects to find solutions to some of the most pressing issues of today and of the future.

The review process started with a literature review and international design for safety questionnaire that informed design thinking methods used in the two symposia. These included mapping and visualising issues that emerged from case studies presented by the international multidisciplinary group of expert participants in the first symposium (figure 1). Insights gained from the first meeting provided direction for a second symposium that focused on the role of design in future safety challenges. This report contains the insights and findings from the panel and expert participants.

Throughout the foresight review process the investigators tested an initial design for safety definition as given below below:

"We believe design for safety enables people and technology to operate safely. Design for safety is the actions taken to ensure that an item, system, system of systems or network is free from adverse impacts on individuals, organisations, communities and the environment, whether these happen as a result of implicit or explicit risks"

Building on the findings of this review, the Foundation will look to identify aspects of design for safety that might provide opportunities or threats to safety, in line with its charitable objectives, and where the Foundation might focus its research and other grant giving to make a distinctive positive impact.

Figure 1: Example of case study from symposium 1, mapping design issues from participants arising across sectors from symposium

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Introduction

Design has the ability to significantly improve safety, reduce risk and save lives. However, we continue to see many examples of safety failures and increasing risks that design could address more effectively.

To frame the concept of design for safety think of the Nils Bohlin-designed seatbelt for Volvo of 1959. Realising that death and injury rates for drivers and passengers were at an unacceptable level the seatbelt was developed as an easy to use intuitive piece of design innovation. Not only was this made a free piece of intellectual property for the automotive industry, saving thousands of lives, it also changed behaviour by reminding us that every time we get in a car and use the seatbelt we are engaging in a risky activity. Design for safety is not only about reducing risk it can also change behaviour and prevent risk. In this review it is not only the shape, function and appearance of objects that are being discussed but also how through design we can influence the behaviours of people.

The activity of design sits between people and technology, and therefore design can enhance the way in which people safely use products, systems and services. However there is a large body of case studies and research which show that there is also significant room for improvement. We continue to see product recalls of mature devices (which have existed for decades) including hairdryers, cars and washing machines, sometimes running into millions of faulty units. The design and manufacture of some of these products, when used as sold, have the potential to cause harm and significant risk to life as seen in the examples of the hairdryer and tumble dryer shown in figure 2.

Such risks are not restricted to consumer products. There are many other examples including building safety procedures whose design can introduce a major risk to life as tragically demonstrated in the Grenfell Tower block failure in London, an example of multiple complex design failures.

Can design be used as a strategic tool to develop safer, more reliable, resilient and sustainable systems and networks? A better understanding of design for safety would allow us to make sure that safety and risk reduction are considered at the earliest stages of developing new products, systems and technologies instead of reacting to failures that have taken place. In these ways design has the potential to reduce safety risks in our daily lives.

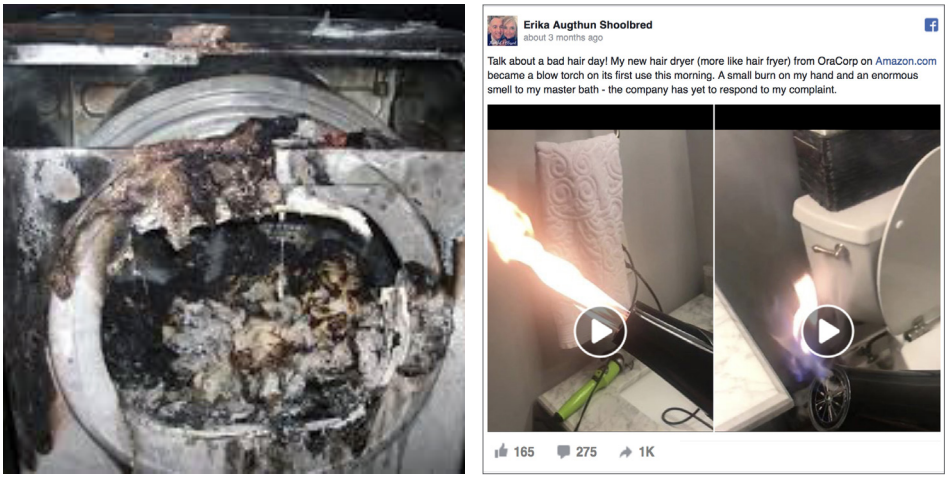


Figure 2: Tumble dryer fire risk recall and faulty hairdryer posted on Facebook.

The 2017 Grenfell Tower fire, London, an example of multiple complex design failures
By Natalie Oxford [CC BY 4.0 (https://creativecommons.org/licenses/by/4.0)], via Wikimedia Commons

What is design for safety?

So far the review has broadly illustrated the risks that design for safety can tackle through interventions that could be delivered either by products or by strategies regulating how people behave in certain situations, for example when interacting with technologies. Now we turn to the process of design to understand where the opportunities for improvement can be found.

To frame the issues and describe the findings the investigators selected case studies which cover three different contexts; equipment design failure, design issues in data-driven infrastructure and community resilience to natural disasters. The lessons apply across both mature and emerging industries where design for safety can have many types of intervention from behavioural, environmental or strategic design approaches. Each case study responds to the sentence 'Who would have thought...' which helps illustrate the design risks.

During the process of developing this review a simple phrase was often repeated - Who would have thought….? This is the type of phrase that often concludes an accident or incident report and paints a clear picture of the type of unexpected outcome of what may be a trivial incident leading to a major safety issue. For example, who would have thought that a barrier added to one section of the River Thames wall to stop people falling into the river could be used as a backrest to sit on the wall (figure 3) and actually increase the risk of falling into the water?

What type of issues are we considering?

Generally speaking there are two types of design issue that we need to consider that regularly occur when understanding design for safety. First, failures can occur when we fail to apply lessons from understanding human behaviour and human interactions with technology. This is particularly evident when unforeseen events, complexities, human behaviours and reactions are combined leading to confused thinking and poor decision making. When people are overly focused on technologies at the expense of understanding human behaviour then this can produce the conditions that easily lead to increased risks.

Second, at the other end of the spectrum, design can significantly remove risk (through human-centred thinking and human systems integration) and improve safety by using innovative technologies, clearly communicating risk, applying lessons and solutions from other areas, and by innovating new safer machines or systems. Foresight processes, blue sky thinking, horizon scanning and a whole range of design methods can be applied to explore safety issues and improve design through analysis, simulation and testing. These design methods and practices (including new ones yet to be developed) can be applied to a wide range of scales from a single product through to an entire system or infrastructure.

Figure 3: Design for safety risk: River barrier can unexpectedly be used as a backrest for sitting on top of the river wall increasing the risk of falls

Case study 1: Who would have thought… an unforeseen situation contributed to equipment failure in the Clipper Round the World Yacht Race

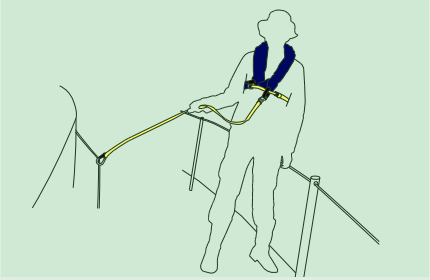
To articulate the close relationship between people and technology and how it might lead to unforeseen events this case study illustrates two accidents both leading to the loss of lives.

In 2016 the Marine Accident Investigation Branch (MAIB) reported an accident leading to the death of a British crew member who died after being washed overboard (overboarding) during a leg of the round the world Clipper Race[1].

The investigation identified the circumstances of a crew member being swept into the ocean caused by the failure of tethering the crew member to the boat. A culture of a lack of supervision over safety and behaviour that lowered the perception of risk played an important role in the crew member's death and reinforced the importance of safety equipment.

[1] MAIB (2017). Report on the investigations of two fatal accidents on board the UK registered yacht CV21 122nm west of Porto, Portugal on 4 September 2015 and mid-Pacific Ocean on 1 April 2016, https://assets.publishing.service.gov.uk/media/58ee0b5040f0b606e7000166/MAIBInvReport07_2017.pdf [Accessed 25 March 2018]

In 2017 another accident in the same race series outlined a safety flaw resulting from the new equipment recommendations implemented after the first incident. The new recommendation was that crew members should wear a harness tethered to a piece of webbing that runs the length of the ship to prevent overboarding in rough seas.



At the time of the accident the crew member was correctly tethered when they were struck by a large wave. However, the tether hook impacted a post on the vessel and deformed due to the impact loading the hook in a direction for which it was not designed, ie laterally. The deformation caused the clip to be released which led to overboarding and the death of the crew member.

The 2017 accident that caused a loss of life outlines how safety equipment design needs to understand the full conditions in which the crew members operate and work. Even though the hook passed longitudinal stress tests, it was not designed to cope with significant load in any other direction.

Both accidents describe how design for safety needs to tackle a variety of different human and technical factors in a complex changing environment. This case study outlines how different changing elements play a role in designing for safety and how these in turn influence people's behaviour in regards to equipment and procedures. Current certifications and regulations cannot account for all situations.

Who would have thought that known and tested safety procedures and equipment would have failed to save a life? From supervisory procedures through to an unexpected design failure because of unforeseen loads, this case study highlights the complexity of both organisational behaviours and the maritime environment within which design for safety needs to operate.

There are differences in how mature and emerging industries understand risk and the degree of knowledge they have developed in the practice of design for safety. Mature industries generally have an understanding of risk which is clearly structured and regulated, while emerging areas are developing and discovering safety issues and how they should be understood and solved. Clearly there are lessons that mature and emerging areas can learn from one other which can lead to a cross-sector approach to design for safety. The diagram in figure 4 illustrates an example of the lessons that can be learnt by mature and emerging industries from the consumer products sector using a comparison between a traditional and 'smart' internet connected kettle. A user will know the risks of using a traditional (mature sector) kettle but will be unfamiliar that an internet connected (emerging sector) kettle can bring additional risks, but of a very different and intangible type.

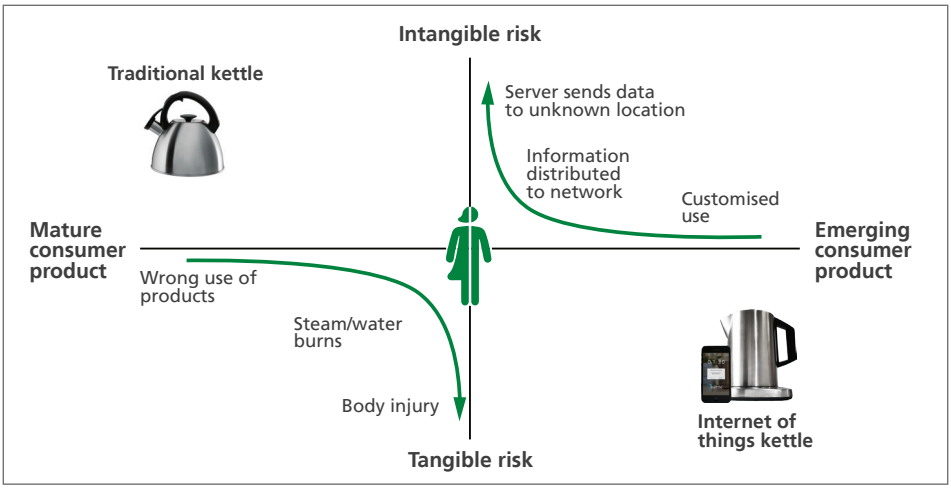


Figure 4: Comparing tangible and intangible risks between mature and emerging consumer product sector

To maximise the potential for learning it is necessary to visualise the core relationships in a way that puts design at the centre of discussions with experts across sectors and disciplines. To achieve this the matrix in figure 5 (overleaf) has been designed to show how lessons can be learnt between mature and emerging industrial areas. Such areas could be in different businesses, for example a start-up or global enterprise, however, both mature and emerging situations could also exist within established businesses and institutions at the same time.

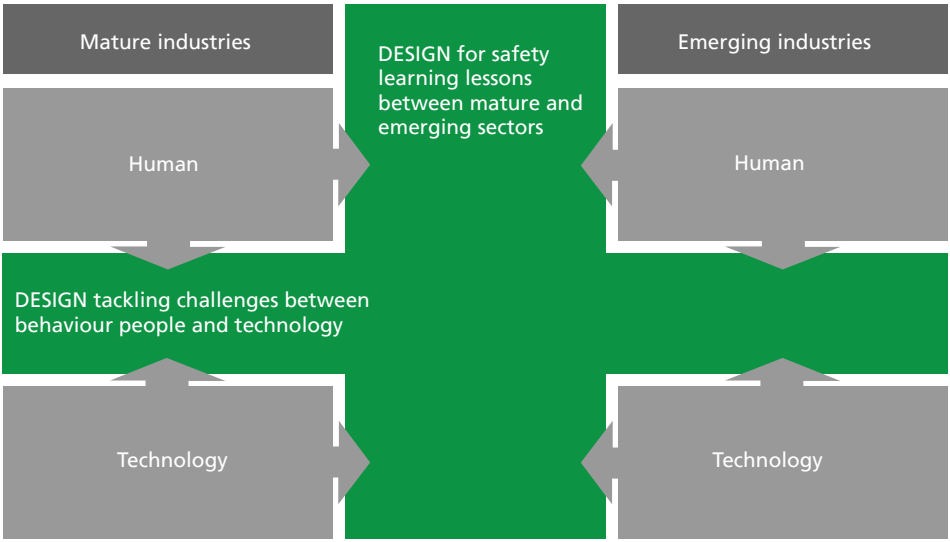


Figure 5: Double axis design for safety matrix putting design at the heart of human-technology and mature-emerging sectors

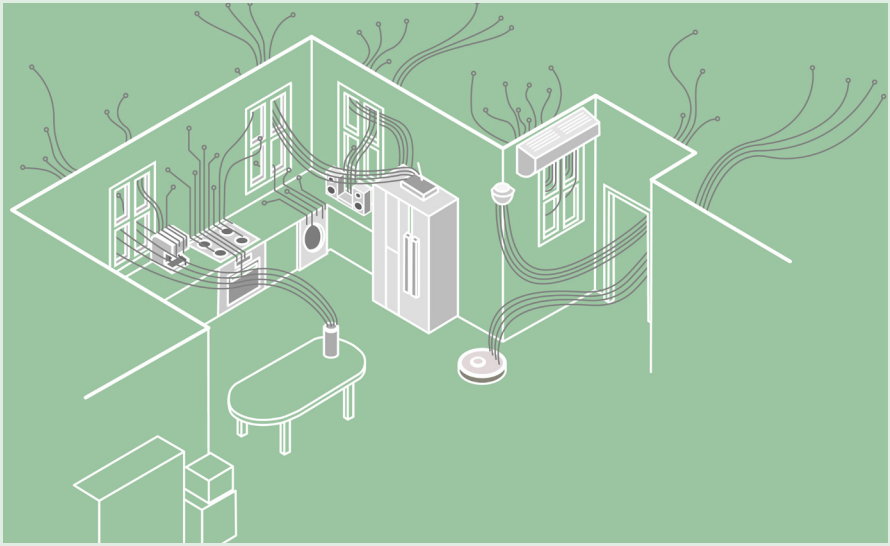
The thinking behind the diagram has been strongly influenced by postgraduate research projects undertaken at The Royal College of Art aligned with Lloyd's Register Foundation's Safety Grand Challenges. In February 2017 two challenges were set focusing on the safe transfer of people between ships at sea[2] and future strategic design solutions aimed at making the River Thames the safest river by the year 2030 with the Royal National Lifeboat Institution (RNLI). Design for safety was understood not only as technology and human operations but expanded to include behaviour change, systemic complexity, safety communication and user journeys[3].

[2] Hall, A; Ferrarello, L; Kann, M, (2017). Safety Grand Challenge: Safe Ship Boarding and Thames Safest River 2030, Report for the Lloyd's Register Foundation, pp 128. ISBN: 978-0-9561364-3-5

[3] Ferrarello, L; Hall, A; Kann, M; Hee Lee, C, (2017). Collaborating Design Risk, IASDR Conference, November 2017, Cincinnati, USA

Case study 2: Who would have thought…improving life in the home could create The House That Spied on Me

Digital technologies can now be found in domestic supplies and appliances and a new critical infrastructure has emerged that connects products with each other via wifi and other networks. It may come as a surprise to some that this infrastructure impacts the integrity of people's lives in relation to privacy and human rights. These devices in people's homes create data which is information. This information travels via the internet beyond the walls of the home and gets distributed to unknown locations for unknown reasons by unknown people. There is very little transparency in how this process works nor the logic or intention that is behind these exchanges or what the implications might be. To live in a 'connected home' means living in the 'house that spies on me'. The House that Spied on Me[4] project details all the invisible data risks that a connected home could be exposed to.



[4] Hill, K & Mattu, S. (2018). House that spied on me, in Gizmodo, https://gizmodo.com/the-house-that-spied-on-me-1822429852 [Accessed 25 March 2018]

The invisible infrastructure that connects our supplies and appliances helps decision making but also puts people under the potential threat of exposing their private lives through data leakage. Data leakage can increase a number of safety risks including the targeting and severity of cyberattacks and ransomware attacks as more personalised information becomes available. It also gives external access to important infrastructure like heating systems, lighting and communications which can imply other information such as an empty home.

Smart products are supplied as black boxes to the consumer and there is little understanding or visualisation of the implications of unsupervised information flow. These products might warn of the physical danger (like electrocution) but say little or nothing about the risk personal data release entails. Designing intangible infrastructure that communicates and engages people to raise awareness of information flow is a strategy that design for safety needs to adopt.

There are very few designs (none apparently on the mass market) that aim at increasing public awareness of personal information released when interacting with connected digital supplies. There is indeed an urgent need for tackling cybersecurity and the related risks through a design for safety communication solution that takes into account how people act and behave. Design for safety could tackle this risk by increasing the sense of awareness and visualising or representing the risks these interactions expose householders to.

Who would have thought a technology designed to automate and improve people's lives would open up their whole private domestic space to access from unknown people in unknown places, with unknown intentions?

What scale of design activity are we considering?

Apart from tackling the risks we understand, the 'known knowns', the two most significant areas for future design for safety are the risks we do not yet understand, the 'known unknowns', such as those that arise from the increasing complexity of technological connections and the risks posed by climate change, and the 'unknown unknowns' that are yet to be identified in emerging industries. Technological risks are emerging and range from the physical risk of drones, robots and autonomous cars to the invisible and intangible risks of artificial intelligence, sensing, surveillance, data security and personal information. While

a complete picture of all the future risks in these areas are yet to be identified (if this is even possible which seems unlikely) there are clear benefits that design can bring to exploring complex areas with vague or seemingly impossible to solve 'wicked' problems.

Future global safety challenges require new types of design methods and approaches needing new combinations of human-centred design thinking delivered through new technologies. For example, communication methods and the ability to instantly broadcast to a global audience has now gone beyond traditional media outlets and exists in social networks and online retail, all of which are changing and building new belief systems and new ways of doing business. By way of example some online retailers provide customers' reviews and ratings for products that they sell; relying on these reviews when making a purchase is an example of a new belief system where you are placing your trust in online reviews. Design for safety is operating in new complex areas including the virtual world.

Communication can create direct physical or psychological stress affecting the behaviours and beliefs of a large number of people who can vastly overestimate the disproportionate risks of the likelihood of disruptive events. It is known that migration, food supplies, water scarcity, terrorism, geopolitical events and climate change can produce disproportionate impacts on human populations[5,6]. These are all issues that can be addressed through safer design.

[5] Burdett, R (2017). Infrastructures of equality versus inequality. in Ruby, I and Ruby, A, (eds.) Infrastructure Space, Berlin: Ruby Press, pp. 306-313, ISBN 978394407184

[6] World Economic Forum (2018). The Global Risk Report 2016, World Economic Forum 13th Ed.

Case study 3: Who would have thought…design for safer environmental systems

Hurricane Sandy Rebuild by Design

In 2012, Hurricane Sandy revealed the fragility of New York City's critical infrastructures to cope with major climate events. In the hurricane's aftermath people lost lives, homes and possessions, power grids failed and transportation systems collapsed.

To protect people's safety against future events President Obama's administration explored a strategy that would not only operate through physical intervention, but instil a culture of safety based on the collaboration and participation of more inclusive parties.

Learning from recent lessons that this collaboration could not be directed only by expert policy makers, engineers or architects, the strategy involved inviting the whole stakeholder community of people affected by the hurricane to tackle reconstruction. Led by Henk Ovink, the Hurricane Sandy Rebuilding Task Force's objective was the identification of strategic interventions developed from co-created ideas fostered by the participation of local governments, communities, designers and experts.

The dialogue would promote a collaborative interdisciplinary approach to safety through creative thinking and design:

- It engaged the public in the decision-making process leading to new environmental policies tackling climate related events.
- It aimed to 'design trust' across experts, communities and government thus increasing the responsibility everyone plays in the system.

The outcome of this dialogue is the Rebuild by Design network[7], which approaches environmental safety challenges through ecosystems made of people, infrastructure and policy collaborating through design principles. For the Hurricane Sandy project, Rebuild by Design launched an architectural competition where multidisciplinary teams came together to develop implementable solutions to the region's most complex needs. Unlike other competitions, the process through which the design took shape engaged local communities, global experts, stakeholders and government who co-created the design proposals.

As a result of being engaged in the process and participating in the actual creative phase, local communities developed a resilience towards uncertainty and a sense of responsibility towards their location. The Rebuild by Design case study illustrates how design for safety strategies need to be dynamic, scalable and have accessible principles that people, experts, governments and institutions can share through a globally diverse network that fosters the exchange of knowledge provided by different user groups and environments.

Who would have thought that government could learn to listen to the community and engage with them in improving resilience to future major climate events?

[7] Ovink, H & Boeijenga, J, (2018). Too Big. Rebuild by Design. A Transformative Response to Climate Change. Rotterdam: NAi Uitgevers / Publishers Stichting, ISBN: 978-94-6208-315-8

What risk is there in design activity itself?

An important question that is infrequently discussed is what risk is there from design to itself. There is a natural assumption that design intrinsically delivers human benefits, yet when we look at design training and the work of designers in practice it is difficult to see widely agreed design for safety methods or principles.

Courses at undergraduate or postgraduate level that focus on design for safety have not been identified. For several decades there has been a strong focus on user-centred design and while this has led to many safer design solutions, its central activity is geared towards satisfying the user instead of intrinsically having safer design. In other words, a safer by design culture needs to focus on more than user-centred design.

The research for this foresight review found very little evidence at either the national or international level to indicate that design for safety practice exists as an area for exchange of ideas and debate. A major risk to design for safety may well be the assumption that designers and industry already have developed methods and practices for future safety challenges, without critically checking if this is true.

Who designs for safety and where is this activity happening?

It might seem a simple question, 'who practices designs for safety?', yet it has become clear that this is not an easy question to answer.

A range of designers, including but not limited to industrial, service, communication and transport designers, understand the concept of designing safe things however very few people in any of these areas describe themselves primarily as 'designers for safety'.

In engineering, clear safety principles and working practices exist although many of these consist of analysing and applying regulations, codes, standards and safety factors for technical constructions. However, engineers also play a role in design.

Finally there are non-designers. These are people whose work contains elements of design however they would not normally call themselves designers and may not even recognise that what they are doing is called design.

Closely linked to this is the interesting question around who owns design for safety? An easy assumption would be designers, yet responsibility for integrating complex technological products and services quickly falls to manufacturers and conformance of products to codes,

regulations and legislation. In a fast developing world manufacturers and regulators are often struggling to keep pace with new technological advancements. Under these circumstances the question of establishing clear responsibility for safe design across industries, sectors and disciplines becomes a challenge.

Making the world's first 3D-printed steel bridge Image courtesy of MX3D

Key points

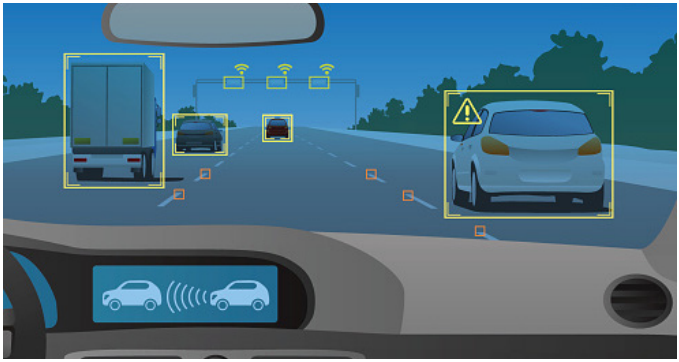
- Risks are influenced by behaviours and culture.
- New technology creates new emerging risks.
- Unexpected situations lead to unexpected outcomes.
- Complexity can increase risk.
- Strategic design approaches can consider the bigger picture.

Sector perspectives

An important perspective in understanding the concept of design for safety can be found from within industry.

Six industrial sectors have been engaged during the review process representing a mix of direct user engagement (consumer products, food products, medical products, transportation technology, national infrastructure and manufacturing technology). Each of these areas includes design activity but in different forms. For example consumer and medical products cover more traditional product design areas whereas food and national infrastructure involve a strategic sector design, advanced design for behaviour change and design of services.

An important perspective in understanding the concept of design for safety can be found from within industry.



An online survey was circulated with a series of key questions, selected to form an initial understanding of views on design for safety, from a range of international experts with diverse backgrounds from government, industry, academia and non governmental organisations. The purpose of the survey was not to produce a large quantity of highly accurate statistical information but to gather insights from a targeted number of experts and use these to initiate discussion and debate in the first symposium.

A total of 75 international cross-sector experts engaged with the process by completing an online survey with the key insights reported in this part of the review.

The survey gained evidence from seven questions where participants were asked to respond to the statement:

Design for safety:

- is a major issue in your sector? (Q1)
- clearly communicates procedures to identify or prevent risk? (Q2)
- is clearly owned across all levels of management? (Q3)
- is recognised as the top operational criterion above costs? (Q4)
- continually assesses risk at all stages of business operation? (Q5)
- combines risk assessment across both technology and human behaviour? (Q6)
- is a system which includes feedback from the general public to improve safety? (Q7)

Respondents from the consumer products sector clearly agreed that design for safety risks is a major issue that is clearly owned, communicated and a top operational criterion (figure 6 below). However, there are some major risks in this sector. For example, the recent Hotpoint

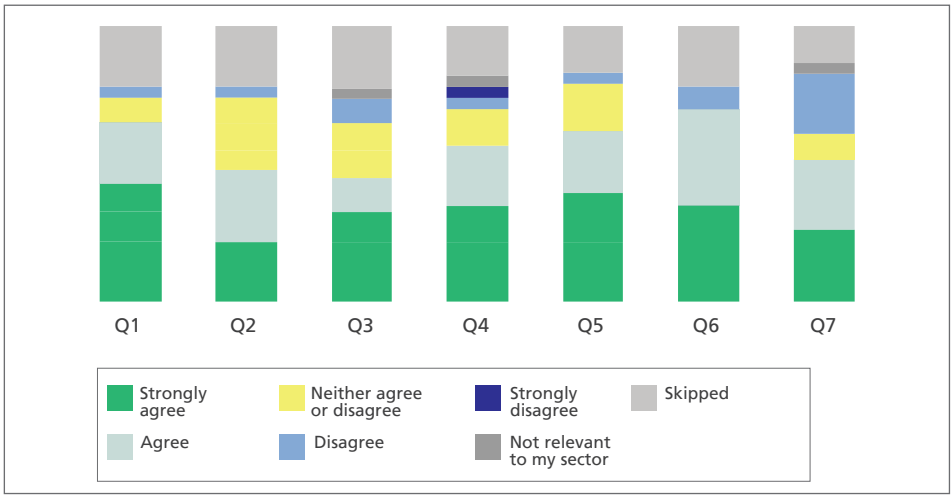


Figure 6: Indicator of responses from the consumer product sector

tumble dryer recall affecting up to 5,000,000 machines[8] and a 'flamethrower'-hairdryer sold by Amazon[9], both mentioned on page 9. These are both examples of products in mature markets suffering extreme design malfunctions causing real risk; the former case, it is claimed, could have caused hundreds of domestic fires. While these may be significant cases that graphically illustrate risk, they can also be interpreted as a very small number of individual risks compared to the billions of products sold globally every year.

The consumer product sector has a particularly strong consumer feedback loop via ombudsmen, regulation, online reviews (Which? Magazine, Amazon etc) and a discerning tradition that has driven high levels of safety overall. However, this does not insulate the sector from a mistaken belief that 'we have got it right' and it remains surprising that global manufacturers in mature sectors can have such major product failures.

[8] Pepin, S, (compiler) (2017), Whirlpool and the product safety system, Westminster Hall Debate, 26 April 2017, House of Common Library, Number CDP-2017-0123, 21 April 2017

[9] Ritschel, C, (2018), Amazon removes hair dryer from website after video shows it shooting out flames, in Independent Online, 2 February 2018. https://www.independent.co.uk/life-style/amazon-hair-dryer-shop-sales-video-flame-on-fire-oracorp-erika-shoolbred-facebook-a8191416.html [Accessed on 25 March 2018]

Sectors without a strong consumer feedback loop include national infrastructure, manufacturing technology and, to a lesser extent, transport infrastructure. Both transport and national infrastructure respondents broadly agreed that design for safety is a major issue that is not clearly recognised; and national infrastructure shows conflicting opinion around continuous risk assessment across all stages of business operation, and that risk assessment combines both technology and human behaviour. Manufacturing technology respondents however reported general agreement that design for safety risks are clearly communicated and owned. These responses are reported in table 1 on pages 27-30 (design for safety recognition by sector).

A second set of survey questions asked respondents to identify what they perceived to be the main design for safety issues in their sector and replies are reported in table 1. Concerns included cyber security, data overload, public uncertainty and complexity. A common factor across the sectors is human behaviour in relation to technology. Crossing all sectors there were terms like; behavioural concerns, understandable to foreigners, effect on human performance, uncertainty vs. risk, shaping behaviours, fake information and personal data. All sectors agree that there is a tension between how humans behave and perform and the technologies provided to do work. This tension results from ignoring human behavioural tendencies and applying a culture of procedures and conformance. Another way to describe this is that the issues are down to poor communication, physical design and more complex issues around the ability to cope with information (cognitive loading), cultural or social differences or mental models that do not align with the technologies supplied for certain tasks.

Key points

- Big differences in how sectors view design for safety.
- Gap between new technology introduction and safe behaviour.
- Need designs for safety developed in a sustainable lifecycle.
- Difficulties understanding complexity and scale of emerging risks.
- Missing principles and ethics for design for safety practice.

Sector	Design for safety recognition by sector
Consumer products	Design for safety is a major issue across the sector and agreement that risks are clearly communicated, owned and are a top operational criterion. **However we continue to see major global consumer product recalls.**
Transport technology	Broad agreement across most questions, however a few representatives from Europe in industry disagree across the board, and more contradiction around ownership of risk. **Design for safety is not clearly understood in this sector.**
National infrastructure	Broadly agree that design for safety is a major issue and clearly communicates a procedure that prevents or identifies risk. **The sector shows conflict around continuous risk assessment across all stages of business operation, and that risk assessment combines both technology and human behaviour.**

Table 1: Main design for safety sector responses

Main design for safety issues		Definitions of design for safety
• Privacy and **cyber security** • Data visualisation on security and risk • Physical motion and control • Mechatronic components in public spaces • Interactive exhibits • Build quality • Antennas	• **Behavioural concerns** • Update of existing solutions • Clear and **understandable to foreigners** • **Ergonomics** - the way we use our devices, even wear our devices (MR, VR) for gaming or productivity	"Zero risk of life threatening effects." "Absolute minimisation of livelihood and ecosystem threatening effects."
• What kind of analysis will lead me to complete realistic body of safety requirements? • Reduce the leading cause of **preventable deaths** (traffic accidents) • **Software risk** mitigation from design solutions to operational procedures • Electronic displays • Universal or standardised systems • **Data overload** • Regulatory frameworks for mariners (ie bridge design)	• Heat, noise and vibration **effect on human performance** • Multiple alarms • Less human operators on ships means risks can be greater • **Complexity** over simplicity of use of lifeboats means they might be killing more seamen than they are saving • Is technology being designed without **diligent research** into its actual effect on humans?	"Consider the entire life-cycle of the system and all its aspects, ie social. , technical and interfaces, in order to design for safety."
• **Uncertainty vs risk** • Public policies		"Inclusive design of urban spaces that understands any user or machine accessing streets and how they behave and how they interact."

Sector	Design for safety recognition by sector
Medical technology	Design for safety is a major issue across the sector and disagreement that risks are clearly owned across all levels and are a top operational criterion. **This highlights a major concern and appears realistic in its self-assessment.**
Manufacturing technology	Design for safety is a major issue across the sector and general agreement that risks are clearly communicated and owned. **Does this indicate a gap between acknowledging ownership verses acting on risks and a deeper understanding of impact is missing?**
Food products	**General agreement with all statements.**

Table 1 (continued): Main design for safety sector responses

Main design for safety issues	Definitions of design for safety
• Reducing **medical error** on hospital wards and emergency mobile healthcare • Understanding the role of design in **shaping behaviours** to improve patient safety • Design to optimise implementation of **safer interventions**	"Design for safety = co-research (define safety problems with front line-clinicians and patients), co-design (generate and iterate concepts) and co-implementation (optimise designs for regulatory and procurement considerations)." "Do no harm."
Three themes: **ownership of the hazard, data protection and human safety** • Personal data • **Protection and ethics** • **Fake information and news** • Technical safety • Reliability • Patient safety	"Design for safety is a process for incorporating construction safety into the design and engineering [of ship building] through early identification and mitigation of risk by engineering, supply chain, project management and planning, supported by the operations team."
• Physical infrastructure design for food safety • **Capacity building** of industry to ensure safe food • Building by government to **ensure safe food supplies**	"The infrastructure (and process) of food and how safety can be designed as an integral part. An awareness of the risks between industries and government to create a better legislation."

Key challenges

A number of challenges have surfaced during this review, the answers to which will help accelerate the opportunities identified.

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What is the current state of design for safety practice?
There are clearly good examples of design for safety practice and growing awareness in industry and other sectors in how design for safety thinking enhances safety. However it is apparent that much work needs to be done to bring together a more coherent picture at an international level of who designs for safety and the methods they use.

What is missing from design for safety?
Design for safety is missing a collation of commonly applied methods and a clear strategic framework to identify which methods are recommended for different situations. In support of these methods there is a need for a set of clearly articulated principles for the activity of design that builds on ethics which can support decision making in complex and contradictory scenarios. There is a lack of clarity of who designs for safety, who takes up this role, where in the process do they engage and to what extent, and crucially who takes responsibility for design.

Do we have clear design ethics and principles?
There is some evidence of broader design ethics and some in relation to safety but these are underdeveloped. Operational principles for design for safety have yet to be formulated in the context of design as framed in this report.

How should design for safety operate?
Design for safety should operate in an open collaborative relationship between all stakeholders including interest groups. 'Designing with' as opposed to 'designing for' should be a central principle to ensure that users' experiences, expertise and insights are drawn into the design process. Design for safety should operate with authority supported with a clear set of operational principles. Design for safety should recognise that creative risk is an important asset in developing new solutions and approaches, and that this can be encouraged to deliver safer final results.

What is the future of design for safety?
Design for safety has clearer and more established practices when dealing with more traditional products and technologies. For more complex systems, emerging technology and behaviour-based applications, there is less clarity. In future we will need to enhance the ability to work in interdisciplinary collaborations and engage with design at strategic and governmental levels when appropriate. The methods selected and developed need to be flexible and adaptable to change and evolving situations. Above all, design for safety needs to be an agile and resource-efficient process driven by a set of principles which can provide a flexible response to new and emerging challenges.

Is design for safety ready to solve the top future safety issues?
Design has some tried and tested methods and practices, and has the flexibility and ingenuity to develop new ones. Today the application of safe design thinking varies across industries and sectors with some having clear approaches whereas in others there appear to be operational complexities that prevent design from making a bigger safety contribution. The future issues for safe design are how to develop more effective operational methods for invisible risks, like data security and artificial intelligence (AI), methods for incorporating human behaviour and systemic dynamic complexity and strategic design skills for guiding large scale responses to climate change, sustainability and disruptive human actors.

Opportunities for a better design for safety culture

In this section we bring together the review contents so far and identify what is needed to promote safer design.

Design for safer human behaviour

We need to embed a better understanding of human behaviour, culture and emotional states into the design of products, services and systems.

This review has identified that human behaviour is one of the major challenges for the future of safe design. Solving this challenge will involve blending technological skills and human behavioural characteristics at the design stage. In order to achieve this we need to understand and develop more powerful methods and practices for improving safety through design by influencing behaviour change. Part of this relies on designing to improve public understanding of personal responsibility and risk.

Design for safety principles and ethics

We need a clear set of principles and ethics to create a design for safety culture.

A common set of principles and ethics is needed to guide the development and selection of design methods. Such principles and ethics will support decisions between the trade-offs of cost and impact that are often needed during the design process.

Safer design methods

We need an agreed overview of design for safety methods that can be applied to current and future design for safety challenges.

This is a significant issue requiring both knowledge and development of different design methods that can address safety challenges. This issue requires multidisciplinary approaches and industrial and institutional sharing of best practices. Specifically these methods take into account a wider consideration of relationships than design for safety has traditionally taken in the past.

Sharing design for safety practices

We need to share best design for safety practices in industrial, institutional and educational sectors through global networks.

A collaboration between international and diverse mature and emerging sectors is needed to learn and share from each other. This could be of great benefit for identifying emerging and future design issues and sharing best practices and new solutions. Design for safety methods need to be flexible to cope with the need for constant change to adapt to new and emerging future risks caused by complexity, the unexpected and changing scenarios.

Design for safety education and training

We need a design for safety practice built on education and training.

The promotion, adoption and training of design for safety methods by both designers and non-designers are currently missing. The training of those with roles that include or overlap design will accelerate the wider sharing and adoption of best practices and design principles to reduce risk. There is fundamental lack of undergraduate and postgraduate professional training in design for safety. This is a major gap in educational provision for training future leaders who will design everything from products and services to strategic infrastructure.

Safety by design for new and emerging industries

We need to learn how to deliver new products and services that are intrinsically safer through design.

At present there is a gap in knowledge for developing design for safety frameworks in new and emerging industries. Closely connected to this is the need for resources for improving the visualisation and simulation of future risks. The whole lifecycle of products and systems often lacks a safety by design mindset that includes construction, repair, refurbishment and decommissioning, all of which are increasingly important parts of a sustainable economy.

The opportunities described in this section can be described as a gap between the development of products, services and infrastructures and the achievement of safer design which is illustrated in figure 7. This summary recognises that reliance on laws, codes and standards alone is insufficient to create safer designs. In order to create safer designs there is a need for a set of design for safety ethics and principles, culture and practices that bridge the gap.

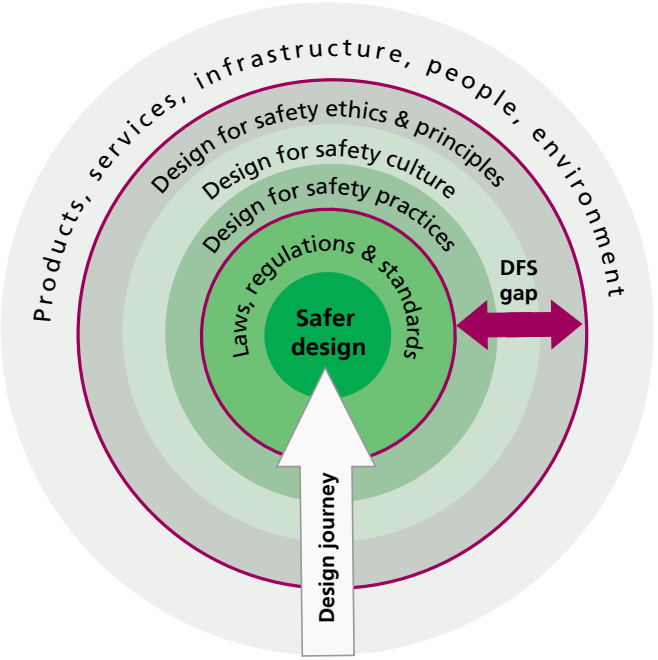

Figure 7: Design for safety (DFS) gap and direction of design project journeys

Aspirational principles for design for safety

This review has identified the need to develop ethics and principles on which a design for safety culture, methods and practices can be established. Such ethics and principles require common global acceptance and this review aims to start a discussion within the wider community to reach this goal.

This review has identified the need to develop ethics and principles on which a design for safety culture, methods and practices can be established.

Following the review process it has been possible to define some preliminary aspirational definitions which it is envisaged will help create the foundations for a design for safety culture.

Definition of design for safety

> "We believe design for safety enables people and technology to operate safely. Design for safety includes the actions taken to ensure that an item, system, system of systems or network is free from adverse impacts on individuals, organisations, communities and the environment, whether these happen as a result of implicit or explicit risks."

Overarching principles

- Design for safety is environmentally sustainable.
- Design for safety actively reduces societal risk.
- Design for safety achieves these through the holistic delivery of its outputs.

These proposed design for safety principles are set out in more detail overleaf in table 2.

Is environmentally sustainable	
Operational principle	**Application**
Design for safety minimises risk to all human life and aims to treat all social, ethnic and geographic demographics equally	Act to minimise risk to life in all situations and consider all stakeholders equally
Design for safety is ethical in its actions and intents and is aware of the scope and consequences of its actions	Think for the benefit of all
Design for safety is resource and cost efficient while delivering the required functionality	Deliver resource efficiency for long term global sustainability of all outputs
Design for safety fully engages with stakeholders and the wider environment	Include people and the environment as a connected system
Design for safety considers full lifecycle ethics	Consider all long-term human and environmental impacts
Actively reduces societal risk	
Operational principle	**Application**
Design for safety has a societally beneficial effect	Prevent socially divisive solutions
Design for safety considers risk to people from both expected and unexpected outcomes	Reduce planned and unplanned risk for all
Design for safety openly shares good design practice	Eliminate repeated risks for all

Table 2: Proposed design for safety principles

Holistic delivery of its outputs	
Operational principle	Application
Design for safety transcends the traditional disciplinary boundaries of design	Multidisciplinary inclusive approach
Design for safety is transparent in all its actions and intent	Communicate with clear motives and methods
Design for safety is user centred	Engage people at the centre of solutions
Design for safety generates and delivers trust and respect throughout all its activities	Seek truth, report truth without favour
Design for safety is up to date and relevant in its context	Adapt to new and emerging risks
Design for safety has clear and unambiguous goals to meet standards and comply with regulation	Comply to standards and regulations
Design for safety has clear and unambiguous responsibilities and accountabilities	Ensure clear management structures communicate who is responsible for what
Design for safety uses critical analysis to deliver definitive answers on exposure to risk	Seek to assess and communicate current and emerging exposure to new risks
Design for safety makes clear its capabilities and limitations of personal, organisational, technical capability and authority	Do not take on more than you are competent to do

Recommendations

This review of design for safety has identified three key gaps which need to be bridged in order for society to fully benefit from safer design: ethics and principles, safety culture and safety practices. Four recommendations are made to bridge these gaps that when implemented will lead to safer designs.

Four recommendations are made to bridge key gaps that when implemented will lead to safer designs.

Identifying future design for safety challenges

There is a need to establish a design for safety research observatory that identifies emerging major safety issues and investigates whether new design methods are required. A key part of this activity will be understanding the most appropriate ways of solving or mitigating these emerging new challenges and the appropriate methods that should be used. A useful approach would be to establish a risk-consequence map applied to an example industrial sector showing where new design for safety issues are needed and if existing types of design method could be applied.

Developing future design for safety methods and skills

Looking forwards there is a need to establish a capability that:

- has expertise in existing design for safety methods
- researches and develops new design methods to address gaps in knowledge
- has an experimental design activity which can compare and test design methods against existing and emerging safety threats
- develops graduate and postgraduate educational programmes that promote state-of-the-art approaches for safer design
- engages the wider community to learn and share experiences and best practice.

Establish a global network of excellence

To maximise the impact of the previous two recommendations an international network of centres of excellence should be established. The global reach of this network will allow emerging challenges to be identified and for best practice to be disseminated as widely as possible to maximise impact.

The unique input of the Foundation

There is already international interest in turning the above recommendations into reality. Before the centres of excellence can be established there is a need for preliminary activity including:

- engaging a diverse and representative range of international industrial and institutional partners
- locating partners from different regions who can bring existing local design for safety expertise to a global level
- a set of initial design for safety global challenges to focus activities of the network
- further research on design for safety practices, ethics and principles, case studies and methods
- experimental projects testing new design for safety methods on emerging risks
- a long term set of milestones, and
- principles for collaboration and exchange.

This would provide the momentum for others to grow and sustain the first two recommendations. The Foundation is uniquely placed to support the initial stages that lead to the establishment of what will be a programme that benefits society at large.

Appendix A: Literature review

The literature review found evidence relating to the remit of the review including the NHS Design for Patient Safety report (Buckle, P et al, 2003), which recommends using design thinking for risk reduction to increase safety in the NHS environment including patients, doctors and nurses. The Office for Rail and Road's Strategy for Regulation of Health and Safety Risks report (Office of Rail and Road, 2017) considers applying design thinking for health and safety in the rail industry. The Internet Way (Grossman, 2015) provided an example of how mature industries can learn from the emerging by looking at the social dynamics created by digital networks. In this context Grossman indicates that safety and trust are factors to consider when designing interactions that communicate risk.

In terms of human factors, examples of methods that can be used for behaviour change in relation to the culture of risk were found. Explaining Risk Perception (Sjöberg, et al, 2004) discusses culture, habits and religion, and the different degrees to which people are exposed to and understand risk. The Royal Navy report, A Guide to Understanding Human Factors and Human Behaviour (Bridger, et al, 2012) played an important role in framing people's behaviour in relation to the environment, the organisation, work dynamics, design of machines, equipment, software and workspace. Proactive behaviour, analysis of behaviour and an analysis of cultural behaviours during risks were examined (Marshall, 2016) (Elliot, 1983) (Health and Safety Executive, 2012) as possible factors that design for safety could take in account. A Design Approach for Safety Based on Product-Service Systems and Function-Behaviour-Structure, describes a model that links human behaviour to the dynamics of the work environment required to deliver a service (Sadeghi et al, 2017). The Haddon-Cave report (2006) highlighted issues of a lack of safety culture and an over reliance on systems instead of vigilant practices. In the context of global risks, recommendations suggest to invest in developing new methods to mitigate emerging risks such as cybersecurity (World Economic Forum, 2016) which is an area that many sectors are attempting to tackle.
The report recently released by the UK government on cybersecurity, Secure by Design, (Department for Digital, Culture, Media & Sport, 2018) mentions design, however this is mainly understood as physical products which protect people from risks like the loss of data and cybersecurity. Henk Ovink's Hurricane Sandy Task Force constitutes an interesting example of design as a strategy to creatively engage local communities, stakeholders, experts and government to reduce risk (Ovink, Boeijenga, 2018) in the event of extreme weather events.

Across the sources consulted there was a general uniformity of understanding and assessment of risk. However if the sources are viewed from a strategic design for safety perspective some contradictions emerge. These contradictions concern the different application of human factors alongside sector specific solutions and practices. This limits

a cross-sector view of safety and a holistic perspective of risk. Cross-sector discussions can help prevent isolated approaches and increase the communication of best practices.

Little evidence was found of attempts to challenge safety procedures and the research identified that the practice of safety and human behaviour, communicating risk and personal responsibility in particular are key points that future design for safety strategies should take into account. However there was evidence of design for human factors and its role in the safety cycle; the HSE research (Health and Safety Executive, 2012) explored how safety can become an approach to behave safely through education and proactive behaviour and A Guide to Understanding Human Factors and Human Behaviour (Bridger, et al, 2012) proposes a model that integrates behaviour in the whole lifecycle of a product from design to manufacture and use.

The main gaps outlined by the literature review are the human errors and lack of clear personal responsibilities relating to managing, supervising, communicating and dealing with risk. Even though the latest safety strategies in the maritime, healthcare and transportation sectors have taken into account behaviour in the environment, there is a design gap in understanding the variable human behaviours in the system and the responsibility of handing over risk to other parties.

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