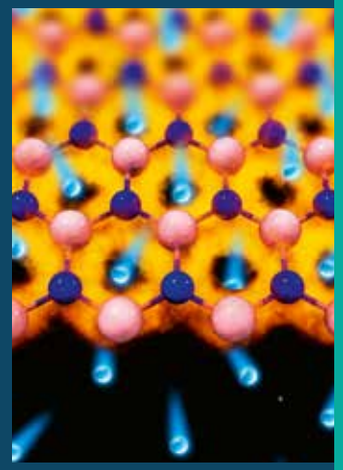
How do we tackle climate change, move towards cleaner energy, provide access to education and produce enough food for a growing population? How do we adapt the way we live in the face of more extreme weather? How can we better prepare for unexpected events like the pandemic? How can we apply emerging technologies safely and beneficially? How can we make sure those benefits are shared fairly?

A Safer World explores ten years of Lloyd's Register Foundation. Detailing the current pressing global safety challenges and how these are being tackled by one of the UK's oldest business organisations, using its international presence and unique ownership model to make the world a better, safer place.



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www.lrfoundation.org.uk

A SAFER WORLD

Foundation

A SAFER WORLD

TEN YEARS OF LLOYD'S REGISTER FOUNDATION 2012–2022

Nigel Watson

Dedicated to Professor Richard Plumbly-Clegg
for his inspirational leadership as the first
Chief Executive of the Foundation.

A SAFER WORLD

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Foundation

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FOREWORD

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The Covid pandemic and the increasing impact of climate change have highlighted our global interconnectedness as never before. No nation is immune from their consequences. These and other challenges make ever more important the charitable mission of Lloyd's Register Foundation and Lloyd's Register Group (LR) to improve the safety of people and property around the world.

This book charts the practical progress made by the Foundation during its first decade. From its inception, the Foundation's priority, as stated in its mission, has been 'enhancing the safety of life and property at sea, on land and in the air, and advancing public education'. Through a series of ground-breaking *Foresight Reviews*, accompanied by equally pioneering *Insight Reports*, compiled by leading authorities, the Foundation identified – and continues to identify – the central safety challenges facing our world and outlined innovative ways of overcoming them.

The Foundation has asked some fundamental questions: How do we tackle climate change? How do we keep people safe from its impact? How do we protect the safety and sustainability of the world's oceans? How can we grow enough food for an increasing population? How can we equip people to improve their life chances in a more uncertain world? How can we ensure people can trust the risk information they seek out? And how can we safely apply advances in technology to help us answer these questions?

OPPOSITE *Nearly a quarter of Bangladesh is less than 2m above sea level, and most people live along the coast, making them vulnerable to the effects of climate change.*

To meet the challenges of the 21st-century world, the Foundation supports the work of leading experts to devise practical solutions to help people in their daily lives. It also promotes projects fostering greater participation in and a better understanding of the engineering, science and technology fundamental to finding ways of creating a more inclusive, sustainable and safer future.

The Foundation takes an active interest in the many projects it supports, and its employees are passionate in their commitment to the mission that it shares with Lloyd's Register – working together for a safer world. As the sole shareholder in Lloyd's Register, the Foundation's funding, which comes from the surplus generated by LR, enables projects to win further funding from other sources. It has forged a worldwide network of partners who share its ethos. Through its work, the Foundation has won an international reputation, bringing the opportunity to extend its influence in pursuit of its objectives.

While some of the challenges you will read about are longstanding, such as safety at sea, others, like disinformation spread by social media, are a product of the last few years. Some, such as robotics and autonomous systems, constantly shift in shape as new evidence accumulates and new findings emerge. Some projects are only just beginning, and it is too soon to judge their practical impact, although the initial results of many of them, such as the World Risk Poll, are already encouraging.

Technology is developing more rapidly now than at any time in the history of humankind. Some of the content of this book will be out of date even as it is published as innovation accelerates. This underlines the importance of the Foundation's mission to ensure that technology is safely applied and harnessed for the common good worldwide. We will continue to identify new safety challenges and work towards solving the most pressing.

As related in this book, the Foundation's story is one that has only just begun. Our next volume will have an even more compelling story to tell.

Muhammad Fadli/Lloyd's Register Foundation

ABOVE *The South East Asia Skills Enhancement Programme (SEASEP) is one example of the Foundation's support to engineering training projects.*

Kevin Frayer/Stringer via Getty Images

INTRODUCTION:
THE CHALLENGES WE FACE

Our planet faces the most challenging century in human history.

LEFT *Beijing's air quality has long been a cause of concern, but the effects of its extreme levels of pollution can now been seen in physical changes to the architecture of the city.*

Since 1760, Lloyd's Register has focused on doing public good and creating a safer, sustainable and more equitable world for everyone.

As we look to the future, how do we tackle climate change, move towards cleaner energy, provide access to education and produce enough food for a growing population? How do we adapt the way we live in the face of more extreme weather? How can we better prepare for unexpected events such as the Covid-19 pandemic? How can we apply emerging technologies safely and beneficially? How can we make sure those benefits are shared fairly?

In working towards the resolution of these issues, we need to harness advancing technology as our ally in making the changes we need to live in a safer, more resilient, more sustainable world. Technology and engineering can enhance our lives or diminish them – and ensuring the former rather than the latter is a constant challenge as industry becomes more sophisticated. This is at the heart of the work supported by Lloyd's Register Foundation, which is using its unique business model, its heritage and international presence to make the world a safer place.

OPPOSITE *Mallika uses biogas made from cow dung for cooking. In 2011, the family paid about US$350 for an NGO to construct a biogas plant. Before this, they used dung and dry leaves for cooking. Using biogas is a much cleaner and cheaper option but not everyone has the means to buy a plant.*

Vidura Jang Bahadur/UN Women Asia & the Pacific (CC BY NC ND 2.0) via Flickr

Sinopix/Lloyd's Register Group

ABOVE *Lloyd's Register's commitment to the highest standards of safety and its values have inspired generations of talented and dedicated people.*

Young Engineers

ABOVE *The Lloyd's Register Educational Trust supported the UK's Young Engineers, which ran clubs for schoolchildren to participate in 'hands-on' engineering activities.*

LLOYD'S REGISTER AND THE FOUNDATION: BUILDING A BETTER FUTURE

Since 1760 the oceans have become a safer place thanks to the work of Lloyd's Register. Ever since the age of sail began to give way to the age of steam, Lloyd's Register has helped international shipping adapt to constant change. In its commitment to the highest standards of safety, its work has known no boundaries, political or geographic, and its values have inspired generations of talented and dedicated people.

As the world's first ship classification society, Lloyd's Register made its name by improving safety at sea, establishing a global reputation for independence and impartiality. This stemmed not only from the work of committed employees but also from the way it was structured. With no shareholders, Lloyd's Register did not distribute profits as dividends. Instead, it reinvested surpluses in the business and the furtherance of engineering and technology.

Lloyd's Register began funding scholarships for students of naval architecture and marine engineering in the 19th century. By the 1930s, this support was international, extended to students in the USA and Japan as well as the UK. By the end of the 20th century, this investment had risen to £400,000 annually. In 2004, Lloyd's Register established an educational charity, the Lloyd's Register Educational Trust (LRET). The Trust funded students in marine technology, safety and systems engineering, research at universities in South Korea, the University Maritime Technology Centre in Southampton, maritime research and education in Greece and a chair in offshore engineering at the University of Singapore. By 2010, thanks to its continued profitability, Lloyd's Register was donating more than £10 million a year to the Trust to invest in science, engineering, technology and transportation education, training and research.

As part of a strategy to assess the risks and ensure the safety of emerging technologies before they were applied, Lloyd's Register maintained regular contact with researchers at leading academic institutions and financed Global Technology Centres in Southampton and Singapore. Its work on safety and the marine environment ranged from studying the effect of propeller noise on sea mammals to improving the safety of container stowage. It continues

to work closely with owners and operators to help them reduce the impact of shipping on the environment. Research was carried out into more fuel-efficient bulk tankers and a partnership was formed with a major shipping operator to investigate biodiesel as an alternative fuel. Lloyd's Register classed the world's first large ferry powered by liquefied natural gas and developed guidance on more environmentally friendly ships and recycling vessels.

As the pace of technological change accelerated, its role in developing rules and regulations became more critical than ever. Lloyd's Register set the standards for safe and sustainable operation, not only for ships and offshore structures, but also for many land-based activities. It was one of the first organisations accredited to independently verify data on airline emissions. It collaborated with the UK's Energy Institute and Health and Safety Executive on devising ways of measuring the impact of the human factor on safety at work; contributed to the guidelines governing standards for the European Marine Energy Centre; and worked with food manufacturers to improve the safety, security and sustainability of food supply chains and participated in the Global Food Safety Initiative. Lloyd's Register's quality assurance business, known as LRQA, became a global leader in its field, ensuring compliance with a variety of quality and environmental standards across a wide range of industries. By the time of its 250th anniversary in 2010, the organisation employed nearly 8,000 people, serving more than 50,000 global clients, surveying ships, inspecting rigs and refineries, and auditing rail networks and production plants.

Two years later, Lloyd's Register was restructured to maintain its mission in safety for public benefit while allowing it greater commercial freedom in a more competitive environment. A new parent charitable foundation, Lloyd's Register Foundation, became the only shareholder of Lloyd's Register Group Limited (LR), that began operating on 2 July 2012. In March 2013, the Foundation absorbed the Lloyd's Register Educational Trust, taking over its commitments. It also assumed responsibility for Lloyd's Register's invaluable library, archive and heritage assets.

Sung-Yeop Jung/Lloyd's Register Group

ABOVE *Lloyd's Register's work on safety and the marine environment included improving the safety of container stowage.*

OVERLEAF *Lloyd's Register set the standards for safe and sustainable operation for ships, offshore structures and many land-based activities.*

Claudio Paschoa/Alamy Stock Photo

The charitable mission of Lloyd's Register Foundation:

'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.'

Alex Block on Unsplash

OPPOSITE *The Foundation protects safety and advances transport and engineering education and research … because life matters.*

Importantly, the Foundation was set up with the same mission and objectives as Lloyd's Register – to protect the safety of life and property on land, at sea and in the air, and to advance transport and engineering education and research. The new Foundation was governed by trustees under the chairmanship of Thomas Thune Andersen, who also continued to serve as Chair of Lloyd's Register. The trustees appointed Professor Richard Clegg, previously Global Nuclear Director for Lloyd's Register's energy business, as the Foundation's first Chief Executive.

On its creation, the Foundation was endowed with over £230 million invested to provide it with an annual income. As the organisation's only shareholder, additional income comes from annual dividends issued by

LR, dependent on the latter's commercial success. In the Foundation's 2014 annual report, Thomas Thune Andersen set out the organisation's philosophy:

> 'The critical infrastructure on which modern society relies – ships, energy generation, industrial plant, railways – is under increasing pressure to satisfy growing demand while innovating safely and protecting lives and the environment. Societies and communities face major challenges linked to issues such as climate change, population growth, energy security, and the availability of food and water. Technology, education and training need to advance rapidly to keep pace with these changes. With our mission to protect the safety of life and property and to advance public education, the Lloyd's Register Foundation has an important role to play in meeting these challenges.'

The Foundation is driven by the same social purpose that has been an integral part of Lloyd's Register since 1760. As the Foundation's Director of Technologies, Dr Jan Przydatek, has put it:

> 'Our work isn't there to create new industries, it isn't about increasing profits for ourselves or anyone else, nor simply out of curiosity; our work is focused on safety for everyone, no matter their geographic location, gender, social status or wealth.'

Stocktrek Images/Thinkstock

OPPOSITE *The critical infrastructure on which modern society relies has to meet growing demand while innovating safely and protecting lives and the environment.*

Mickey Lee Mediamixer.co.uk/Lloyd's Register Foundation

ABOVE *The Foundation's regular international conference brings together a wide range of experts to discuss how to make the world a safer place.*

OPPOSITE *Lloyd's Register and the Foundation were at COP26 in Glasgow in 2021, raising awareness of the vital importance of the oceans for the planet.*

In the decade since it was formed, the Foundation has funded a series of ground-breaking projects. They range from emergency preparedness training for the Royal National Lifeboat Institution and fire engineering education in South Africa, to establishing the science of Data-centric Engineering and fostering an international nanotechnology knowledge network. In a shared safety mission with Lloyd's Register, utilising the latter's experience, expertise and global presence, the Foundation is reaching out across the globe. It works in partnership with leading academic institutions and other global organisations, including the United Nations Global Compact (which pledges commitment to implementing sustainability principles), Food and Agriculture Organization and International Labour Organization. Lloyd's Register Group and the Foundation were represented at the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow in 2021, helping to raise awareness of the vital importance of the oceans for the planet. The Foundation holds a regular international conference; in May 2022 it hosted the Safer World Conference, both in person in London and online, with more than 1,500 delegates and 30 thought-provoking international speakers.

As Andersen noted, the world faces growing challenges linked to climate change, population growth, energy security, and the availability of food and water. Furthermore, without developments in technology, education and training, humanity will struggle to keep pace. The Foundation has a crucial role to play in meeting these challenges and this publication aims to provide a snapshot of the evolving situation as the Foundation reaches its 10th birthday. Before looking at these projects in more depth, let us examine the key safety challenges with which the Foundation engages.

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CLIMATE CHANGE

Arguably, the most important global safety challenge is the impact of climate change. The science has been understood since the early 19th century, when the French physicist Joseph Fourier described the nurturing greenhouse effect of Earth's atmosphere. In 1859, Irish scientist John Tyndall noted the warming effect of carbon dioxide (CO_2) emissions. Just over a century later, in 1962, expanding industrial activity and an increasing global population caused these carbon emissions to reach almost 10 billion tonnes a year. Furthermore, there was now incontrovertible scientific proof that CO_2 concentrations in the atmosphere were rising. By the 1980s, the adverse impact of the warming climate was being taken more seriously. In 1988 the Intergovernmental Panel on Climate Change was formed and, at the 1992 Earth Summit in Rio de Janeiro, developed nations agreed to stabilise their greenhouse gas (GHG) emissions to a level that would avoid harm. By then global GHG emissions were nearly 32 billion tonnes a year. Progress to implement the 1992 convention has been complex and slow. A key target now is to limit the amount of global heating and COP21 in Paris in 2015 marked the first time that countries pledged to meet a target; COP26 in 2021 confirmed this as 1.5°C above pre-industrial levels.

The world's population has almost doubled since 1992, approaching 8 billion in 2021, a figure anticipated by the UN to reach 10.9 billion by the end of the century. By 2019, global GHG emissions reached 50 billion tonnes a year.

The colossal rate of change in global warming has had a visible impact on the planet. Climate change fuelled world crises that directly affected 235 million people during 2021. More frequent extreme weather has had a devastating effect. In India, severe flooding caused by unusually heavy rainfall set off extensive landslides. In Texas, freezing temperatures brought power blackouts, a shortage of safe drinking water and the closure of factories

Pali137/Thinkstock

OPPOSITE *CO_2 is the main GHG but others – methane, nitrous oxide and trace gases – contribute a significant amount of warming.*

supplying crucial silicon chips for cars and computers. In Kenya, heavier rainfall steadily enlarges Lake Turkana, submerging the local community's fresh-water pumping station, destroying fishing sites and inundating ancestral burial grounds.

Furthermore, the rapid melting of the world's glaciers, the disappearance of Greenland's ice sheets and the collapse of polar ice shelves is predicted to continue to raise sea levels. A US interagency report published in 2022 stated that sea levels around the US were projected to rise by up to 25 to 30cm by 2050. With 10% of the world's population living on land less than 10m above sea level, rising waters could swamp low-lying islands such as Kiribati, Nauru and Tuvalu in the Pacific and the Maldives in the Indian Ocean. More than 3 billion people live within 62 miles (100km) of the coast, yet heavily populated coastal areas are among the least well prepared for the consequences of more frequent cyclones, hurricanes and typhoons, causing loss of life and damage to homes, workplaces and other infrastructure. In 2019 Typhoon Hagibis tore through Japan, killing more than 100 people and causing US$15 billion worth of damage. Typhoon Rai, the last of 15 typhoons to strike the Philippines in 2021, disrupted the lives of more than 4.5 million people.

Yet as sea levels rise, wildfires have become more frequent and widespread as other areas of the world become drier. In recent years they have devastated parts of Greece and Turkey, France and Italy, striking inland as well as along the coast. (The European Environment Agency estimates that since 1980 severe weather has cost European nations half a trillion Euro and taken the lives of as many as 142,000 people.) In Australia during 2019–20 bushfires broke out over an area of 31,000 sq. miles (81,000 sq. km), killing 25 people, devastating wildlife and costing the economy US$70 billion. In 2021, British Columbia in Canada experienced both extreme heat – killing 500 people – and extreme flooding – displacing thousands. At the same time, record high temperatures across the USA were a factor in nearly 59,000 wildfires, which scorched approximately 12,700 sq. miles (33,000 sq. km) of land. The searing heat left more than 100 people dead in the usually temperate state of Washington, which also suffered heavy snowfall during the winter and destructive floods during the autumn. Phoenix, Arizona, recorded a temperature of 43°C (109°F) on 53 days, which led to the deaths of almost 200 inhabitants.

ABOVE *The Republic of Kiribati in the Pacific is one of the world's lowest-lying nations. Many of the its 33 atolls and coral islands are no higher than 2m above sea level, making them extremely vulnerable to rising sea levels.*

Eric Sales/Asian Development Bank (CC BY NC ND 2.0) via Flickr

ABOVE *A Mongolian herder cultivates plants adapted to drought to achieve more resilience to extreme weather changes.*

This series of events has shifted policy in North America from mitigation and emission reduction to climate adaptation. In October 2021, the US government published climate adaptation and resilience plans, while Washington State is introducing a series of climate adaptation measures, including resilience planning within water system plans. The 2021 COP26 summit agreed to double the funding for climate adaptation – a broad term, covering everything from planting trees in individual gardens to relocating entire populations from increasingly uninhabitable terrain. In British Columbia, State Premier John Horgan stated in his budget speech for 2022: 'We must act now to protect people and communities against future climate disasters.'

Between 2008 and 2021, rising temperatures, droughts, wildfires and floods displaced an average of nearly 22 million people. The impact will only worsen if the world continues to get warmer. And it is the poor who suffer most from the resulting poverty, migration, hunger, gender inequality and scarcer resources. Zambia has 1.2 million undernourished people, with 60% of the population living below the international poverty line. Women produce 60% of the country's food supply but families headed by women endure worse poverty than those headed by men. Malawi faces a similar situation, with climate change causing delayed, heavy and destructive rainfall, infertile soil and wrecked harvests. In Burundi, where 90% of people rely on small-scale farming, only a third of the land is suitable for cultivation because of drought, floods and landslides. And gender inequality is rife – while women make up 60% of Burundi's farming workforce, they account for only 20% of positions in decision-making bodies.

As we can see, climate change is perhaps the most important safety challenge facing the world today – not only in the adverse weather effects as detailed above, but also in its shattering impact on global food production.

FEEDING THE WORLD

Climate change makes food production more unpredictable. For example, in 2021 Madagascar saw the country's worst drought in decades, which left some 500,000 children seriously malnourished. Furthermore, a crisis in any one country or region can cause international instability. In 2007–08, a drought in Australia, followed by regional crop failures, set off a world food crisis. Global food prices doubled, leading to protests in at least 13 countries. In 2010–11, Eastern Europe's very hot summer led to lower wheat yields, forcing up food prices, contributing to the social unrest that precipitated the uprisings of the Arab Spring. All this makes feeding a growing population more difficult when many people already go without sufficient food, and often the effects of activities in one part of the world are hardest felt by already vulnerable communities living elsewhere.

Moreover, the way we produce our food is accelerating climate change and depleting the environment. Food production makes up 30% of GHG emissions. In some low- and middle-income countries, such as Somalia, Nepal, Madagascar and Vietnam, irrigation for agriculture accounts for more than 90% of fresh-water withdrawals. Soil degradation because of intensive agriculture and forestry is a major concern, seriously harming the mycorrhizal fungi networks vital to life on Earth. Making up to half of the living mass of soils,

CIAT/Neil Palmer (CC BY SA 2.0) via Flickr

Hemera Technologies/Thinkstock

they are a major global carbon sink (something that absorbs more carbon than it releases). They are essential for the healthy life of plants, supplying them with nutrients, protecting them against drought and helping to fight off pests. Their destruction hinders our attempts to reduce carbon emissions – one estimate suggests these networks suck up 5 billion metric tonnes of carbon every year (equivalent to the output of the USA) – and injures life on Earth. Many European trees, for instance, are more prone to disease, pests and climate change as a result of the damage to the mycorrhizal networks. Soil degradation also puts at risk the food security of billions of people.

Our disruption of the natural world can have many unforeseen consequences.

OPPOSITE *A Colombian farmer with his crop destroyed by parrots whose migration patterns, influenced by climate change, now coincide with the end of the maize season.*

ABOVE *In some low- and middle-income countries irrigation for agriculture accounts for more than 90% of fresh-water withdrawals.*

RIGHT *The major causes of land degradation in Ethiopia are the rapid population increase, severe soil loss, deforestation, low vegetative cover and unbalanced crop and livestock production.*

Georgina Smith/CIAT (CC BY NC SA 2.0) via Flickr

CONSERVING THE OCEANS

Climate change and human activity are a challenge in the oceans as well as on land. Covering 70% of the planet and producing half the world's oxygen, the oceans are an important carbon sink, absorbing at least a quarter of the world's emissions. However, as climate change warms the oceans, ice melts more rapidly and sea levels rise. Warmer oceans deplete oxygen levels, making breathing for marine life more difficult. The human-driven increase of carbon dioxide in the atmosphere means there is more CO_2 dissolving into the oceans causing ocean acidification. This reduces the amount of carbonate, the key building block in seawater for crustacea and coral to make their shells and structures. Another hazard is the global discharge of plastic waste into the oceans. Every year, 8 million metric tonnes finds its way into the oceans. Plastics, which make up 80% of marine debris, break down into small particles, causing harm to fish and other species. Their ingestion causes them to be passed on to humans through the food chain. Both polar regions are known to have been polluted by tiny plastic particles since the 1960s.

One particular incident demonstrates how interconnected the marine environment is with our own. In May 2021, a chemical cargo ship, the *X-Press Pearl*, caught fire off the coast of Sri Lanka. Tons of tiny plastic pellets were released into the sea and washed up on local beaches, resulting in a ban on fishing along miles of coastline. As well as seriously harming the marine environment, the incident was disastrous for local fishers, depriving them of their livelihoods.

The oceans also provide 3 billion people with their primary source of protein and 60 million people their livelihoods through fishing and aquaculture, almost all of them in developing nations in Asia and Africa. And yet the oceans are being overfished and have been for decades – a third of the world's fish stocks are depleted. Too many vessels catch too many fish, often using destructive methods such as bottom trawling. Overfishing is also often encouraged by government subsidies, endangering once common species such as bluefin tuna. Boats are sailing further from the coast and staying longer at sea, while catches continue to diminish.

q phia (CC BY 2.0) via Flickr

ABOVE *The biggest challenge facing the oceans is acidification, which is affecting many different species. Plastics, which make up 80% of marine debris, also break down into small particles, causing harm to fish and other species including coral.*

OVERLEAF *The oceans are being overfished and have been for decades – one-third of the world's fish stocks are depleted.*

Paolo Cipriani/iStock/Getty Images Plus

CREATING A MORE EQUAL WORLD

In addition to the challenges related to climate change, for billions of people, surviving in privation remains a daily struggle. Too many people still suffer from extreme poverty, defined by the World Bank as surviving on an income of less than US$1.90 per day.

Furthermore, the poorest workers suffer the worst conditions, often in the most deprived parts of the world. The garment industry, for instance, is characterised by low wages and long hours, minimal workers' rights and poor regulation. The preventable deaths of 1,136 garment workers caused by the collapse of Rana Plaza on the outskirts of Dhaka in Bangladesh in 2013 prompted long-overdue international and regional action to improve working conditions and safety. Commercial fishing is likewise low paid and poorly regulated, as well as being one of the world's most dangerous occupations. It has been calculated that 24,000 deaths occur in the industry every year, but this is now regarded as a gross underestimate, and research is continuing to establish a more realistic figure. Since there are no common international standards, fishing vessels in many countries, according to the International Maritime Organization, are lightly regulated, if at all, and many fishers go to sea with little safety training or safety equipment. In many parts of the world, when a fisher loses their life at sea, their family risk destitution. This is particularly the case in Southeast Asia where, in a competitive, labour-intensive, low-margin industry, some operators, desperate to cut costs, use forced labour. The violence and cruelty faced by one Thai fisher during four years at sea are vividly described in Vannak Anan Prum's 2018 book, *The Dead Eye and the Deep Blue Sea*.

Hindered by climate change and conflict, efforts to reduce poverty have been set back further because of the global financial crisis and the worldwide Covid-19 pandemic. During the pandemic, the proportion of the world population living in extreme poverty rose from 8% to 9%, the first increase since the Asian economic crisis of the late 1990s. According to the World Bank, many of the new poor are found in countries with high poverty rates, with 82%

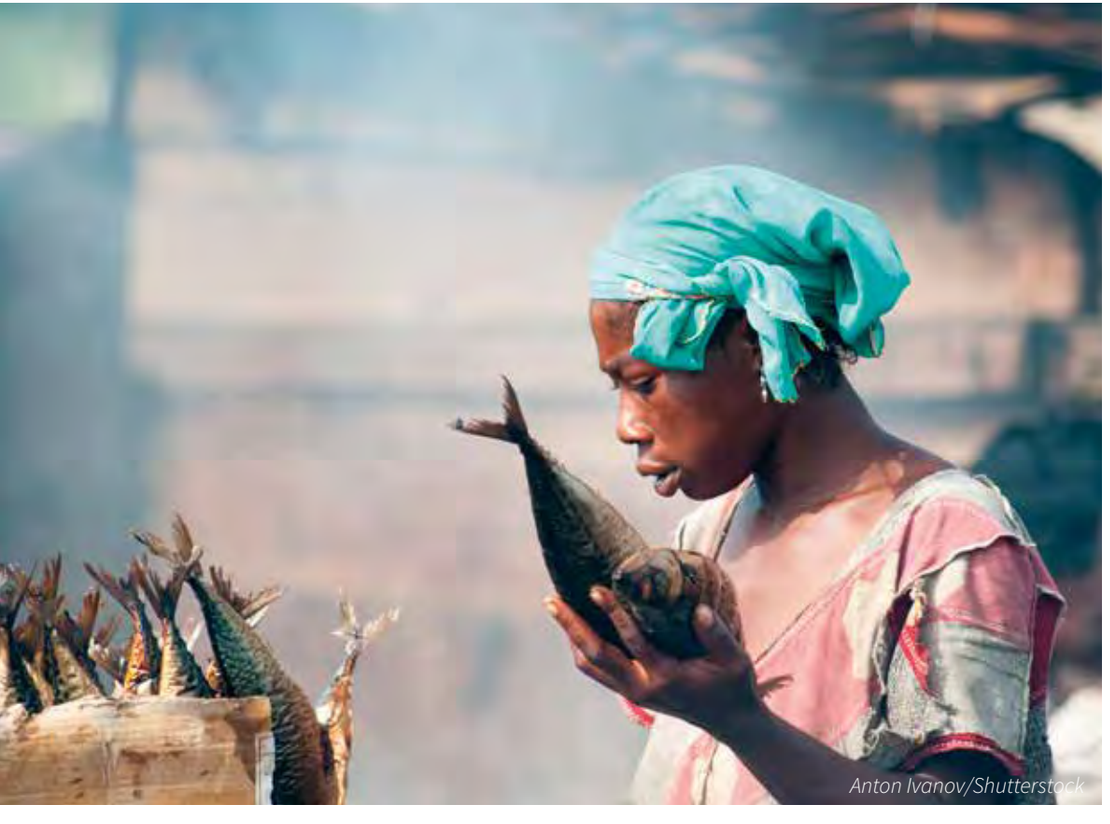
humphery/Shutterstock

LEFT *The poorest workers suffer the worst conditions. The garment industry, for example, is characterised by low wages and long hours, minimal workers' rights and poor regulation.*

OPPOSITE *When a fisher loses their life at sea, their family risks destitution. This is particularly the case in Southeast Asia.*

Sutipond Somnam/Alamy Stock Photo

BELOW *Many women earn less for working longer hours than men.*



Anton Ivanov/Shutterstock

in middle-income nations like India. While some progress is predicted post-pandemic, particularly in stable states, poverty will again be concentrated in fragile countries and the poorest parts of sub-Saharan Africa.

Women have been seriously affected by these crises. The international charity Oxfam calculated that in 2020 women lost income of at least US$800 billion because of Covid-19. They are more likely to have precarious jobs. Many found their education cut short, depriving them of future opportunities to improve their incomes.

According to the United Nations (UN) more women will be in poverty by 2030 (121 women per 100 men) than in 2021 (118 per 100). This reflects continuing gender inequality, with many women earning less for working longer hours than men, while many more remain excluded from the workplace, lack access to finance and cannot own property. Reducing poverty remains paramount if barriers to improving life chances are to be removed.

Reducing poverty remains paramount if barriers to improving life chances for women are to be removed.

THE FOURTH INDUSTRIAL REVOLUTION

One of the barriers to improving life chances is the disparate degree of access to the digital and data technology transforming the way we live. So extensive is its impact that it has become widely known as the Fourth Industrial Revolution, a term popularised by Klaus Schwab, founder of the World Economic Forum, in his 2016 book of the same name.

'We are looking at a world of continuous disruption through digital and cyber-physical advancements that are impacting every aspect of our society,' wrote Thomas Thune Andersen in 2016. As Chair of Lloyd's Register and the Foundation, he was well placed to judge the effect of such advances. While the digital revolution rivals previous industrial revolutions in its global impact, it differs in two respects.

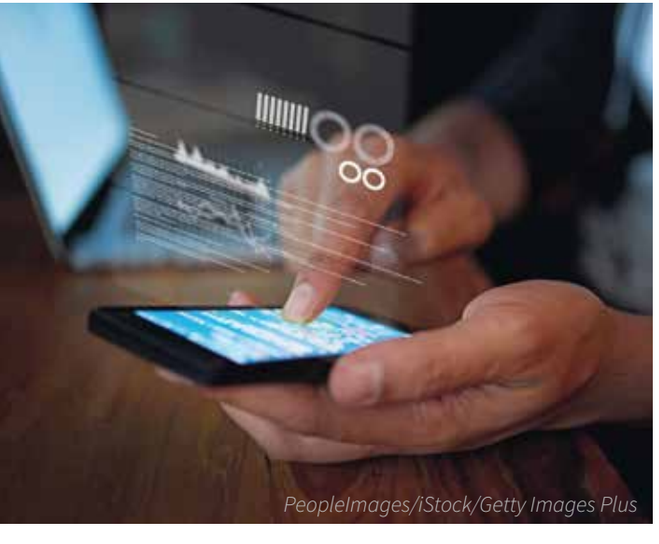
BELOW *Access to the digital and data technology revolution is transforming the way we live.*

exclusive/Alamy Stock Photo

First is the pace of change. Emerging technologies are being adopted so rapidly that their safety is often untested prior to implementation. Covid-19 has accelerated the speed of adoption in sectors from construction to energy and healthcare. Regulators struggle to develop rules and standards before new technologies are applied.

For example, big data and the internet pose a threat to personal privacy. Intensive surveillance was once an activity confined to state security authorities. Today, it has become a public-private partnership, with big tech companies often complicit in co-operating with national security agencies. Everyday consumer electronics have the in-built capacity to track the daily movements of any individual. Moreover, digital systems are vulnerable to outside attack. Hospitals, pipelines, power grids and meat plants are just a few of the examples of infrastructure brought to a halt by the action of hackers.

The second difference from previous revolutions is the convergence of multiple emerging technologies to create complex interdependent systems operating in almost every sphere of human life. While many systems work without fail, others have proved vulnerable, and their failures can be catastrophic, particularly when they impact other systems that were not previously regarded as being connected.



PeopleImages/iStock/Getty Images Plus

LEFT *Emerging technologies, for example big data and the internet, pose a threat to personal privacy.*

OPPOSITE *Complex systems can be vulnerable, as shown by the 2003 blackout that affected almost the whole of Italy.*

Alessia Pierdomenico/Reuters /Alamy Stock Photo

In 2003, for instance, a series of major power blackouts occurred across the world. Italy was brought to a standstill one autumn weekend when a falling tree knocked out a major transmission line. As other power lines succumbed, trains were halted, traffic lights stopped, lifts stalled, lights went out, mobile phone networks went down and hospitals resorted to emergency generators. The blackout, as one senior official suggested, may have been an exceptional, extraordinary event, but this and other events exposed not only the frailty of the interconnected systems sustaining our day-to-day lives, but also our failure to prevent them from breaking down in extreme circumstances.

It is critical to understand how these systems work, how to make them safer and how to manage them if they fail. The challenge is ensuring that education, training, governance, standards and regulations keep up with the rapid application of innovative technologies. Improving knowledge and skills is essential not only to make sure smart technology works for us but also to take advantage of new job opportunities being created as technology reshapes the world of work.

Digital technology has revolutionised how we work. Like every industrial revolution, it has eliminated some jobs and created new ones. In many manufacturing environments, robots now carry out operations once performed by humans, under the management of multiskilled and technically qualified operators. While in 2019 it was estimated that since 2000 the world has lost 1.7 million jobs to industrial automation, it was reckoned by McKinsey in 2017 that nearly 16 million new ones had been created.

What differentiates current technological trends from the past is the capacity of artificial intelligence and machine learning to fulfil tasks previously requiring human intellect. This will have a major impact on many middle-income occupations across a wide range of sectors. A recent report from consultants PwC estimated that 30% of all jobs are at risk from automation by the mid-2030s, with the most vulnerable employees being those with low educational attainments. Women are most likely to be affected in the short term, but in the longer term more male dominated occupations will be susceptible. Automation is expected to have the greatest impact in finance and transport, while healthcare and education, more reliant on social skills and human interaction, with women making up the vast majority of the workforce, will be least affected.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Rido/Shutterstock.com

Further, many jobs put on hold as economies faltered will never reappear. Instead, employers have turned to automation. During the Covid-19 pandemic, robots were rapidly introduced to take over the work of people who were unwell or self-isolating, from cleaning floors in airports to chatbots in call centres. As Oxford academic Daniel Susskind, author of *A World Without Work* (2020), observed in *Time Magazine*: 'Machines don't fall ill, they don't need to isolate to protect peers, they don't need to take time off work.'

Yet the World Economic Forum predicted that what it called 'the emerging professions' would create more than 6 million new jobs between 2020 and 2022. The highest growth, the Forum asserted, would come from data and artificial intelligence, the green economy and cloud engineering and computing.

OPPOSITE *In many manufacturing environments, robots now carry out operations once performed by humans.*

ABOVE *Sectors which are more reliant on social skills and human interaction are expected be least impacted by automation.*

The challenge is ensuring that the workforce of the future has the knowledge, skills and flexible approach required for a more automated environment. Covid-19 highlighted the absence of retraining for many employees displaced by automation as governments failed to grasp changing trends in employment. Giving people the right skills is critical for the equitable distribution of the benefits of the digital age, as Schwab pointed out in his 2018 book, *Shaping the Future of the Fourth Industrial Revolution*:

> 'In a world where essential public functions, social communication and personal information migrate to digital platforms, governments – in collaboration with business and civil society – need to create the rules, checks and balances to maintain justice, competitiveness, fairness, inclusive intellectual property, safety and reliability.'

More recently, writing in the World Economic Forum's *Global Technology Governance Report* 2021, Schwab has stressed how we must ensure that emerging technologies 'remain human-centred and serve society as a whole, providing everyone with fair access'.

This concern has led some to hail the emergence of a Fifth Industrial Revolution in pursuit of a more balanced and collaborative working relationship between people and smart technology, where the emphasis is on service to humankind rather than on the momentum of technology and commerce. In combination with better education and training, smart technology can help to enhance safety in traditionally hazardous occupations such as construction or fishing on which millions of people depend for their livelihoods.

Technological innovation can undoubtedly enhance our lives. Nanotechnology, the science of very small things (see page 196), has given us improved pacemakers, fine filters to capture toxic particles from air and water, longer-lasting batteries and more efficient solar panels. The combination of big data – the immense volume of data generated by our digital society – and rapid analysis from powerful computers has countless benefits, from helping healthcare professionals offer more personalised treatments to

Gerardo dalla Torre/g3r1/iStock/Getty Images Plus

analysing images of glaciers to calculate the rate at which they are melting. Additive manufacturing, or 3D printing, can cut energy consumption and material wastage in construction and build everything from the tiniest medical implants to a bridge for pedestrians and cyclists recently constructed in central Amsterdam (see pages 204–209).

ABOVE *Safety in traditionally hazardous occupations can be helped by smart technology.*

DISINFORMATION

As the world has become more interconnected and with instant communication, it becomes harder for people in society to discern opinion from fact, and disinformation from trust. One of the less attractive aspects of the digital revolution is the ease with which digital media can be manipulated and false information rapidly gain ground. From conspiracy theories that vaccinations can alter an individual's DNA to the claim that drinking bleach was a cure, incorrect or inaccurate information intended to mislead reached a new peak during the Covid-19 pandemic. Disinformation circulated about every aspect of the disease from its origins and transmission to treatment, worsening the impact of the pandemic by influencing behaviour, encouraging risks, causing harm and placing greater pressure on global health systems.

According to a 2020 study by the International Telecommunications Union and the United Nations Educational, Scientific and Cultural Organization, disinformation causes harm because it can 'confuse or manipulate citizens, create distrust in international norms, institutions or democratically agreed strategies, disrupt elections, or paint a false picture about key challenges such as climate change'. The inability of nation states to regulate the global tech platforms enabling the flow of information across international boundaries was reflected in the call by 130 UN members in June 2020 for all states to take countermeasures against disinformation.

And yet digital media is indisputably an invaluable resource for verifiable information from trusted sources. In recent years, the epidemic of disinformation has encouraged attempts to reinforce existing trusted sources and ensure where possible equal access to verified sources of reliable evidence. While the internet powers the spread of false information, it also gives easy access to knowledge, helped by ever faster internet speeds.

Digital media can be easily manipulated, thereby allowing false information rapidly to gain ground.

BELOW *Disinformation about Covid-19 worsened its impact by influencing behaviour, encouraging risks, causing harm and placing greater pressure on global health systems.*

Matt Smith/Alamy Stock Photo

Ericky Boniphace/Shutterstock

ABOVE *By December 2021, only about 9% of people in Africa had been fully vaccinated against Covid-19.*

THE PANDEMIC

At the time of writing, the Covid-19 pandemic is the most immediate global crisis. Indiscriminate in its impact, it has disrupted almost every aspect of human life: millions have died and the livelihoods of millions more have been damaged; the next generation have suffered interrupted education; and vaccines have been unequally distributed, disadvantaging more populous, poorer countries. While freedom has been restricted, safety has been at the forefront of people's minds.

According to a survey charting global resilience to Covid-19 in the world's 53 largest economies, by US media group Bloomberg, the least resilient countries were among the world's least advantaged. At many points during the pandemic the bottom 10 comprised largely African or Asian countries, including Thailand, Malaysia, the Philippines, South Africa, Indonesia and Vietnam. The pandemic has demonstrated the need for community resilience in the most dramatic, life-changing and life-threatening manner. The need for the precautionary principle – to adopt measures not to stop the spread but to reduce its impact – has been critical, ranging from the development of vaccines to wearing masks and homeworking. The world has learned the hard way, with most nations completely unprepared to react to the rapid worldwide spread of a highly infectious and deadly virus. Furthermore, governments have been hindered by inconsistent and mixed messaging – see the discussion above regarding social media and disinformation – often for political reasons, which has made tackling this worldwide crisis much more difficult.

OVERLEAF *Adopting measures to reduce the impact of Covid-19 has been critical, from the development of vaccines to wearing masks.*

Robert W/Alamy Stock Photo

Matthew Childs/Reuters/Alamy Stock Photo

LEFT *Thousands of lorry drivers spent Christmas 2020 in their cabs on the UK's M20 motorway. France closed its border after the UK warned of a fast-spreading variant of Covid-19.*

Covid-19 has also shown the fragility of global supply chains, with cargo unable to enter or leave ports and their crews isolated for months at a time. On the other hand, it has also demonstrated the positive side of technologies, such as digital communications, which made it possible for many millions to carry on working. It has also highlighted how technology can be swiftly harnessed for public benefit when the political will exists: the unprecedented public and private investment in the search for effective vaccines has opened the door to use the same research, data and technologies to combat other diseases.

The story that follows shows how work supported by the Lloyd's Register Foundation is helping to address these global safety challenges.

CHAPTER 1:
CLIMATE CHANGE

Rising temperatures have a domino effect on people's lives and entail devastating consequences.

LEFT *Due to climate change, many extreme weather events, such as heat waves and droughts, could become more frequent and more intense in many parts of the world.*

We already see more frequent storms. The most destructive can pass over in just a few hours, but the havoc they wreak may take years to repair. The poorest countries will be the worst hit. There will be longer droughts and more intense wildfires. Rising sea levels threaten low-lying coastal and island communities.

Climate change disrupts plant and animal life, whether on land or in the sea, destabilising the balance of the natural world, reducing the productivity of domestic crops and animals and threatening fish stocks. Reduced yields and higher prices increase the challenge of feeding the world's population. Some islands and coastal regions will become inundated because of rising sea levels, while some inland areas will become inhospitable because of more extreme temperatures, forcing people to move in their millions, increasing the potential for conflict. In Sudan, for example, the advancing desert is eroding land for cultivation, creating intense competition among those who plant crops and graze animals, exacerbating the country's civil conflict. The cost of climate change can be measured not only in greenhouse gas (GHG) emissions but also in the damage to people's lives, from families in Bangladesh who have lost loved ones in the floods and Yemeni girls forced into child marriage because their parents can no longer afford to keep them, to families in the Canadian north-west whose homes have been entirely consumed by wildfires.

OPPOSITE *In Bangladesh, with the sea encroaching on his home, a man salvages bricks to build another place to live.*

Moniruzzaman Sazal/Climate Visuals Countdown

Nabin Baral/IWMI (CC BY-NC 2.0) via Flickr

ABOVE *In Nepal, farmer Sabita uses solar panels to help power irrigation. Technology has improved agricultural production and reduced the hours spent carrying water.*

The world cannot withstand the economic and social consequences of further rises in temperature.

Reducing carbon gas emissions to near zero is daunting. Emissions fell during the first year of the Covid-19 pandemic because of weaker economic activity but only by 5% and at a significant cost to people and their livelihoods. But to sustain the future of a growing global population, traditional carbon-emitting energy sources must be replaced by affordable alternatives. And this change, without the commercial self-interest which drove past transitions, must be achieved more rapidly than any other in human history. Simultaneously, communities and their infrastructure must become better able to withstand the more frequent shocks that climate change administers, whether by improving infrastructure or giving people the resources they need to sustain their livelihoods in a time of radical change. We must adopt more sustainable ways of producing food. Water supplies must be better managed. These objectives, achievable through harnessing innovation with technology, will create a fairer, more sustainable and safer world.

Organisations such as Lloyd's Register Foundation are helping to support initiatives to tackle many of these challenges. The Foundation's reputation enables it to play an influential role at the highest level, such as at the COP26 conference, where critical decisions for our future are made. The Foundation is helping to mitigate GHG emissions in its projects to develop alternative forms of energy on land and at sea. It has backed a variety of innovative approaches to making communities and critical infrastructure more resilient to climate change. Projects for the better management of water resources and a greater understanding of the risks to food security have also been funded by the Foundation. One of its most significant initiatives is the Institute for the Public Understanding of Risk (IPUR) in Singapore, which is helping people across Asia to make more balanced decisions about risk in a changing world. As part of a challenge-led, evidence-based research strategy, the Foundation has published a series of influential reviews to raise public awareness of major global safety challenges. These *Foresight Reviews* and *Insight Reports* have covered topics such as food safety, design for safety and regulatory systems, sharing engineering data and safety in the fishing industry. With its emphasis on education, the Foundation also helps spread the findings of Foundation-sponsored research, translating technical findings into terms better understood by the public and more likely to engage policymakers.

ENERGY TRANSITION AT SEA

With oceans covering 70% of the globe, the world economy relies upon shipping, which carries 90% of traded goods. But the traditional fuels powering modern shipping release over 800 million tonnes of carbon into the atmosphere every year. Although this amounts to around 3% of total global carbon emissions, this exceeds, for instance, the output of many European nations. With marine trade forecast to triple by 2050, it is crucial for shipping to reduce its carbon and other GHG emissions by adopting low- or zero-carbon alternative energy. In 2011, the International Maritime Organization set a target for the industry to reduce GHG emissions by at least 40% by 2030, compared with emission levels recorded in 2008.

This was challenging for a traditionally conservative industry, and no solution was prescribed for achieving the objective. Yet every effort needs to be made to execute an industry-wide commitment to adopting one of the most radical changes in the history of shipping, driven by the urgent need to mitigate global warming rather than by economic self-interest. Given the usual lifespan of a vessel is in excess of 20 years, it is essential that all new ships are equipped with climate-friendly technology. In parallel, regulations need to be devised to ensure untried and high-risk technologies can be applied safely.

Classification societies – which are responsible for assuring the safety of the world's shipping – are playing a leading role in this revolution. Lloyd's Register foresaw the changes that were needed a decade ago. In 2009, the organisation was already committed to the concept of sustainable shipping, noting in *Horizons* magazine:

> 'Sustainable ships are ships that have a long-term future that will meet future trading requirements, will burn less fuel, cost less to run and be safer to operate. This will be the era of low carbon shipping.'

Anucha Sirivisansuwan/Moment via Getty Images

ABOVE *The world economy relies upon shipping which carries 90% of traded goods.*

THE SHIPPING INDUSTRY AND CLIMATE CHANGE

Today, as in the past, Lloyd's Register and the Foundation continue to influence the thinking of the shipping industry. By the early 2000s, LR was already involved with a series of sustainable energy projects involving natural gas, methane gas, biodiesel, hydrogen-powered fuel cells, wind-assisted propulsion and photo-voltaic cells. LR worked closely with owners, operators, builders and manufacturers as the industry moved towards more efficient and environmentally friendly ship designs and propulsion systems. It contributed to the growing number of national and international research programmes aiming to reduce shipping's carbon footprint. Lloyd's Register was part of Shipping in Changing Climates (a UK government-sponsored research project led by University College, London), and worked with partners such as the University Maritime Advisory Service and the Global Maritime Forum on low-carbon technology and zero-emission vessels. LR was among the classification societies that helped formulate the Poseidon Principles in 2019. This agreement was reached with major international ship-financing institutions, which committed to considering the industry's carbon emissions target in any lending or investment decisions.

kallerna (CC BY-SA 4.0) via Wikimedia Commons

ABOVE *The ferry* Viking Grace*, classed by LR, was the first passenger ship of its size to run on completely sulphur-free liquefied natural gas (LNG) when it came into service in 2013. In 2018, LR also approved the safety of the installation of a rotor sail, making it the first passenger ship in the world equipped with this type of sail to use wind power.*

ABOVE *Decarbonising international shipping will also help to decarbonise global supply chains.*

Obviously, the 2020s would be a critical decade for accelerating the maritime energy transition if new vessels commissioned from the early part of the decade were to be equipped with the appropriate technology. Since 2020, three major decarbonisation centres have been established in London, Copenhagen and Singapore to provide the industry with leadership insight and evidence on the safe adoption of low- and zero-carbon energy systems.

The first of these centres was the Maersk Mc-Kinney Møller Center for Zero Carbon Shipping, established in June 2020 with funding from the A.P. Møller Foundation. The second, the Lloyd's Register Maritime Decarbonisation Hub, was founded with support from Lloyd's Register Foundation in October 2020. A third was launched in 2021 when the Global Centre for Maritime Decarbonisation was opened, funded by the Maritime and Port Authority of Singapore and covering Asia-Pacific. All three centres draw on the expertise of partners from a wide variety of maritime organisations, providing impartial and independent advice for the industry. They work closely with each other, underlining the importance of global collaboration in tackling climate change. In the words of Nick Brown, LR's Chief Executive: 'We either all win in saving the planet or we all lose.'

The Hub was one of the first major collaborations between LR and the Foundation, and furthered the Foundation's objectives by drawing on LR's expertise. The Hub was set up to help the shipping industry understand the various energy alternatives, the safety risks involved and how to manage them. The work of the Hub, however, has wider implications. Targeting all the parties with an interest in moving shipping to alternative energy, from designers, builders and owners to ports, charterers, fuel producers and finance houses, it offers valuable lessons for other industries struggling to reduce emissions. Moreover, by helping to decarbonise international shipping effectively it will also help to decarbonise global supply chains.

Research carried out by the Hub established that for shipping to help limit the rise in global warming, the first large-scale deep-sea vessels running on zero-emission fuels needed to be in service by the mid-2020s, with zero-emission vessels the standard for the industry by 2030. The major challenge was not only ensuring the technical viability of a safe zero-emission ship but

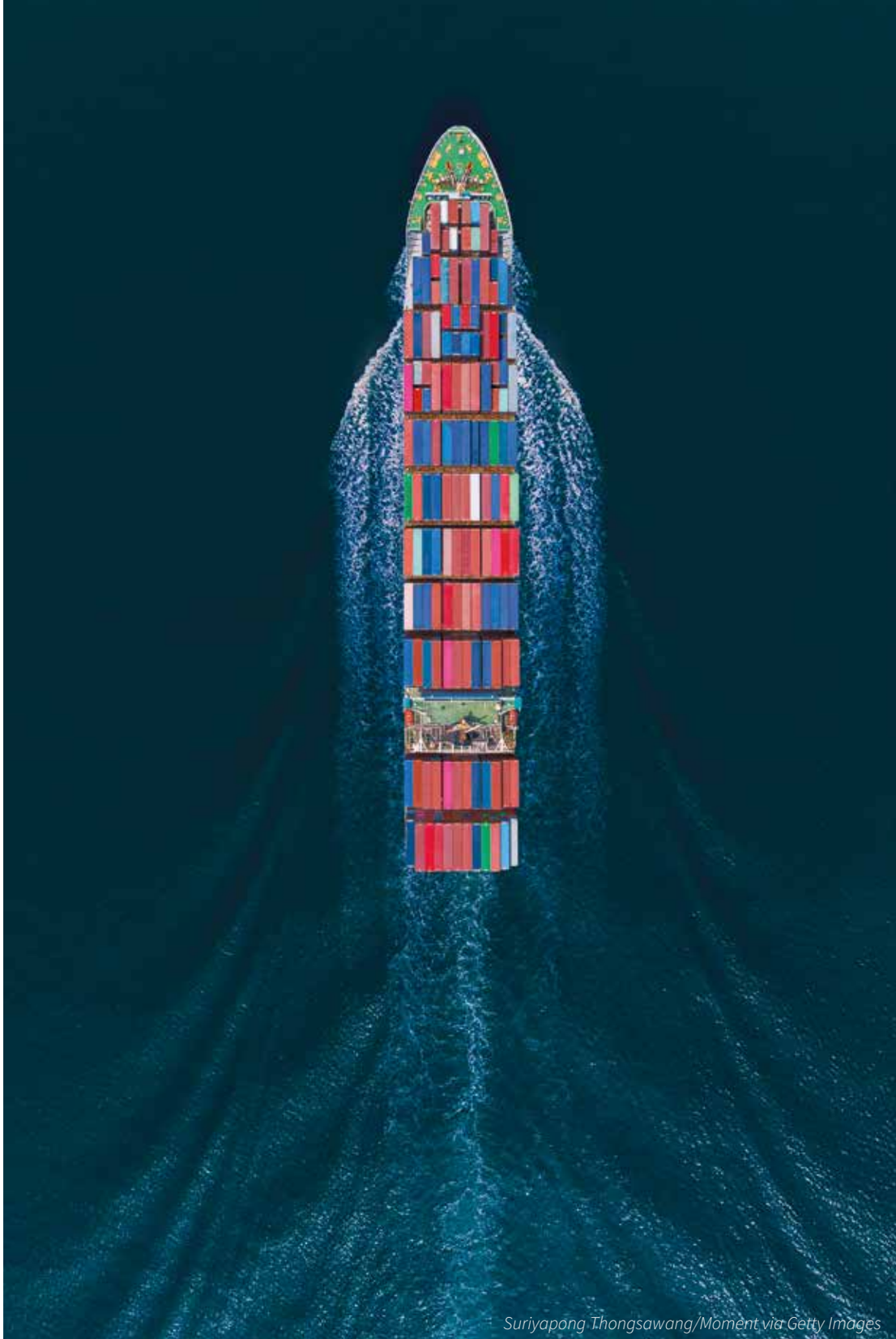
also that the necessary land-based infrastructure was in place to support the transition. Arising from this, the Castor Initiative, with LR as one of the partners, was launched in 2019 to develop a design for an ammonia-fuelled tanker. It is planned that the first zero-emission vessel will be in service by the mid-2020s.

LR and the Foundation also came together at the COP26 conference in 2021 to encourage governments to enact policies and offer incentives for private investment to support research into zero-emission vessels and the most appropriate ships for international trade routes. The work of Katharine Palmer, seconded from LR as the shipping lead for the UN's High-Level Climate Champions initiative, was instrumental in mobilising the shipping community to reach an agreed position, working together to achieve a greater impact and create more confidence. The Clydebank Declaration, an initiative led by the UK government and signed by 19 nations, was launched at the conference and committed its signatories to setting up green maritime corridors, that is, specific routes decarbonised throughout from ships to land-based infrastructure. Identifying the volume of zero-carbon energy for each route will help governments promote renewable energy production in key ports.

Lloyd's Register Group

LEFT *'Shipping decarbonisation's process is not merely a "nice-to-have" – it's an urgent imperative.' Katharine Palmer, Shipping lead for the UN High Level Climate Champions.*

OPPOSITE *The Clydebank Declaration will set up green maritime corridors – specific routes decarbonised throughout from ships to land-based infrastructure.*



Suriyapong Thongsawang/Moment via Getty Images

ABOVE *The Resilience Shift programme was set up by the Foundation and Arup to ensure critical infrastructure remains robust enough to withstand changing local weather conditions.*

SAFETY FOR A SUSTAINABLE FUTURE

Hydrogen is one of the alternative fuels for shipping under investigation. In 1807, hydrogen powered the world's first internal combustion engine built by the Franco-Swiss inventor François Isaac de Rivaz. The only major deterrent to its wider use today is the safe containment of zero-carbon fuels in or around major infrastructure either onshore or on board.

Pilot projects are underway with shipping companies around the world, and marine fuel cell makers are researching the possibility of fuel cells capable of generating up to five megawatts of power, enough energy to propel nearly three-quarters of all ships in service today. Fuel cells powered by hydrogen have the potential to decarbonise transport of all kinds. They are already used to power forklift trucks and as a source of backup energy, and the airline industry is also researching their potential use. However, implementing hydrogen as a sustainable fuel at scale is challenging. The Foundation is supporting the participation of the UK Health and Safety Executive's Centre for Energy in a major EU project exploring the safe use of hydrogen for this purpose.

Climate change also calls into question the safety of critical infrastructure. The Foundation established an innovative initiative, the Resilience Shift programme, in partnership with the international engineering consultancy Arup, with the objective of ensuring critical infrastructure remains robust enough to withstand changing local weather conditions. The programme is developing the concept of resilience engineering (see Chapter 3) to create the safe and sustainable infrastructure systems of the future.

Aline Tong/Shutterstock

LEFT *The damage caused to health and climate by open burning, such as here in Africa, is a global concern.*

As noted in the Introduction, the climate crisis affects the safety of workers worldwide. This is one of the subjects of research carried out by the Centre for Transport Risk Management at Imperial College, London, another Foundation-supported initiative. In Taiwan, for example, the Centre is employing wearable technology to monitor the health of motorcycle delivery drivers, who are compelled by higher temperatures to keep their visors raised, exposing them to air pollution.

The Foundation's interest in improving the safety of workers was furthered through support for the Engineering X Safer End of Engineered Life programme, led by the UK's Royal Academy of Engineering and linked with the UN's High-Level Climate Champions campaign. The widespread practice of burning waste, its impact on GHG emissions and the health and safety of the workers involved, was raised as a global concern at COP26. The Engineering X project supports two waste management leads in Africa raising awareness of the damage caused to health and climate by open burning and promoting better practices. 'By bringing together the evidence and the community,' said the Academy's Chief Executive, Dr Hayaatun Sillem, 'we were able to find a new level of engagement which we hope will lead to an improvement in safety but also in sustainability.' The Academy is also partnering with the International Solid Waste Association to help make waste management more sustainable.

REGULATION FOR A SAFER WORLD

In addition to the kind of initiatives detailed above, regulations are also evolving around the world to meet the climate change challenge. For instance, expanding seaweed cultivation is one of the answers to feeding a growing population. In some parts of the world, however, climate change is forcing cultivation into deeper waters, making the process more dangerous. Therefore, it is vital that suitable regulations and training are developed to protect the workers whose livelihood comes from growing seaweed.

The evolution of regulations to meet changing global conditions was the subject of one of the series of *Foresight Reviews* published by the Foundation. It demonstrated how lessons could be learned from the past. In the Netherlands, for instance, regulations to help protect this low-lying nation from flooding were first put in place after the disastrous floods of 1953. The Delta Programme regulated matters such as the height of dykes and coastal management. Rising sea levels, higher temperatures, drier weather and more frequent storms mean floods would be even more destructive today.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Estimates maintain that 60% of the country, including its major cities and economic activity, is under threat. The government's objective is to ensure that the Netherlands is climate-proof and water-resilient by 2050. The revised Delta Programme forms part of that national plan. New risk-based flood protection measures consider the potential impact of any inundation. Greater emphasis is placed on securing sufficient supplies of fresh water. Sustainable floating spaces are an option for housing and infrastructure, like Schoonschip, Amsterdam's floating urban neighbourhood, completed in 2021.

OPPOSITE *In the Netherlands, regulations to protect the nation from flooding are being revised to respond to the risk of rising sea levels.*

ABOVE *Also in the Netherlands, regulations are in place for floating spaces as an option for housing and infrastructure.*

OVERLEAF *In some parts of the world, seaweed cultivation is moving into deeper waters and new regulations will be vital to protect workers.*

Farley Baricuatro (www.colloidfarl.blogspot.com)/Moment Open via Getty Images

FOOD AND WATER

Climate change puts natural resources under stress. Water supplies and food production have always been susceptible to the vagaries of the weather. Climate change increases the probability of harm.

By 2050, 1.6 billion people will be at risk from floods, which lead to contamination; and 3.2 billion people will live in areas where water shortages will become acute as lakes, reservoirs, wetlands and floodplains dry up. One in four people will live in countries experiencing shortages of fresh drinking water.

The same weather extremes disrupt food production. Heavier than usual rains are producing more frequent swarms of locusts, destroying crops across large parts of Africa and Asia. Extreme heat in the USA threatens crops and livestock and in 2020 a severe windstorm devastated corn and soybean production in the Midwest. Without effective adaptation, global crop yields are forecast to drop by 30% by 2050.

Extreme weather events are no longer infrequent. Such stress is particularly acute in centres with growing populations. Without decisive global action, the poorest and most vulnerable will be worst hit, harming their health, destroying their livelihoods, and destabilising their societies. This is one area in which the Resilience Shift programme mentioned above is helping communities to strengthen their capacity to manage their natural resources more sustainably. After the drought of 2017–18, for example, Resilience Shift worked with the city of Cape Town to learn from its water crisis and disseminate valuable lessons to a global audience. Resilience Shift has since worked on the development of the City Water Resilience Approach, a methodology that encourages new thinking to ensure urban water resilience in cities worldwide. The approach was implemented in 2019 with pilot projects in Addis Ababa, Miami and Hull, UK. The project team have collaborated with these cities and five more globally to understand their urban water system, governance, interdependencies between water and other systems, and the factors

OPPOSITE *Lessons have been learned from the 2017–18 drought in Cape Town.*

Tim Wege/Alamy Stock Photo

LEFT *Weather extremes disrupt food production. Heavier than usual rains are producing more frequent swarms of locusts, destroying crops across large parts of Africa and Asia.*

Chad Staddon/UWE, Bristol

contributing to resilience.

Another Foundation-supported initiative with the objective of improving how we look after our fresh water supplies is the International Water Security Network (IWSN), led by the University of the West of England. Established in 2013, with the University of Arizona and Monash South Africa, the network's collaborators include the Asian University for Women, charity WaterHarvest working in India and the National Association of Professional Environmentalists in Uganda.

Combatting climate change requires us to change our behaviour. People still lack the knowledge they need to bring about change. Investing in better public education is therefore vital. For instance, with funding from the Foundation, five leading museums in the UK, Brazil and India set up the Feeding Tomorrow project in 2021. This investigated the public perception of risks to food security created by climate change. It discovered that many people are unaware of how food production is responsible for one-third of GHG emissions. While there was widespread support for more sustainable ways of producing food, people also wanted more information to help them make better choices about their food. The research is being shared with other organisations working with the public on the future of food in an age of climate change.

OPPOSITE *IWSN projects in East Africa have involved assessing water quality in groundwater and rainwater harvesting systems.*

RIGHT *In India, the Feeding Tomorrow project, working with student focus groups and others, found little knowledge of the links between food supply and climate change.*

Sam Barker Photography/Lloyd's Register Foundation

PUBLIC ENGAGEMENT

A critical factor behind all these and other measures is ensuring they have public support. It is also crucial to have a flow of reliable information about climate change and how it can be combatted. There is a disconnect between the urgency given to the climate crisis by some governments – there are differing attitudes between developed and developing nations – and international organisations and many people's perception of the risk. One of the Foundation's most important initiatives, the World Risk Poll (see page 249), carried out in 2019, revealed that nearly half of us still believe climate change is not a very serious threat, and one in ten people remain convinced that climate change has nothing to do with human activity.

Without widespread support at every level, the world will struggle to take the steps needed to keep the planet safe and reduce the impact of climate change on the most vulnerable. Building wider public support for action on climate change and improving understanding of its risks are therefore critical to protecting those most vulnerable.

This is one of the objectives of IPUR. Jointly endowed by the Foundation and the National University of Singapore, the Institute is researching how better communication and understanding of risk influence people's behaviour. IPUR, together with the charity Sense about Science, is developing the concept of risk know-how, compiling practice-based insight to help people make more informed decisions and judgements about risk. For example, Mongolia is among the nations least affected by the changing climate, but research has revealed that many people were disproportionately anxious about the crisis. Outreach work conducted by the Institute is helping civil servants in the region to better communicate risk so that communities have the necessary tools and information to make informed choices.

One in ten people remain convinced that climate change has nothing to do with human activity.

Solmaz Daryani/Climate Visuals Countdown

ABOVE *Global warming increases the risk of drought – such as in Afghanistan pictured here – yet the World Risk Poll revealed that nearly half of us still believe climate change is not a very serious threat.*

Public engagement is at the heart of the concept of 'citizen science', which uses public participation and collaboration in scientific research to increase scientific knowledge. This is central to a project supported by the Foundation in England. Led by the Museum of London, the Coastal and Intertidal Zone Archaeological Network (or CITiZAN) is helping local communities throughout the country record and monitor their local coastlines. Under threat from constant erosion, rising sea levels and climate change, the English coast bears witness to the country's long maritime heritage, and the project is engaging thousands of volunteers across the country to take part in documenting this heritage before it is lost. The project also uses the extensive maritime archive held by the Lloyd's Register Foundation Heritage and Education Centre (HEC), bringing the Centre's records to a new audience.

Margaret Clavell/Shutterstock.com

LEFT *Sunrise at the shipwreck of the SS* Nornen *at Berrow, Somerset. Under the CITiZAN project, thousands of volunteers are taking part in documenting England's maritime heritage before it is lost.*

PreciousPhotos/Shutterstock.com

CHAPTER 2:
FEEDING THE WORLD

The World Resources Institute estimates that the world must produce 60% more food for a population of nearly 10 billion by 2050.

LEFT *In 2021, one in ten people around the world faced hunger.*

After declining steadily for a decade, around the world hunger is on the rise, affecting nearly 10% of people globally. In 2021, 828 million were suffering from hunger and the number of people who were food insecure, lacking the regular nutritious food needed to live a healthy life, rose to around 2.3 billion. Yet the planet produces enough food for everyone. The ocean covers 70% of our planet but contributes to less than 3% of our food in terms of calorie supply. We are still in the Stone Age when it comes to food from the ocean, acting mostly as hunter-gatherers.

AGRICULTURAL APPROACHES

The intensive approach to agriculture pursued since 1945 – which is costly in terms of energy, environmental degradation and greenhouse gas (GHG) emissions – is unsustainable in an age of climate change and population growth. Yet agriculture, in its broadest sense, provides food and income for most of the world's poorest people, three-quarters of whom live in the countryside.

Agriculture can adapt to climate change and become more productive. Producers must adopt more sustainable practices, plant resilient local crop varieties and employ traditional local knowledge. Working with rather than against nature will also help sustain the planet's biodiversity, agriculture's essential ally. Farmers seeking to adapt have a growing list of options, from the use of small robots to avoid the adverse impact of heavy tractors, to the application of rewilding or regenerative agriculture.

Giacomo d'Orlando/Climate Visuals Countdown

ABOVE *Sergio Gamberini created Nemo's Garden off the coast of Italy, the world's first underwater greenhouses, to pilot a model of sustainable agriculture. This cultivation uses minimal energy and protects crops from pests and harsh weather.*

OVERLEAF *Over 3.5 billion people around the world rely on rice as a staple part of their diet and it provides livelihoods for nearly 1 billion people.*

Riccardo Lennart Niels Mayer/Alamy Stock Photo

Witchaphon Saengaram/Moment Open via Getty Images

Producing enough food sustainably is only part of the challenge. It must also be produced safely. In 2004, 160 nations voted at the UN to make safe food a human right. Unsafe food is costly in terms of lost productivity and health. The World Bank estimated the cost to low- and middle-income countries as at least US$100 billion annually. Every year nearly one in ten people fall ill after eating contaminated food, resulting in 420,000 deaths annually. Unsafe food fosters disease and malnutrition, places healthcare systems under strain and dents growth in trade and tourism. In emerging economies, the demand for fresh food in growing urban communities brings the risk of contamination and a fall in nutritional value.

Food must also be produced fairly. Reference has already been made to forced labour in the Southeast Asian fishing industry (see page 41). Other commodities known to contribute to the rise in modern slavery include coffee, tea, sugar and cocoa.

Food production accounts for one-third of annual GHG emissions. Of that, nearly a third comes from livestock and fisheries and more than a quarter from crops. Cattle and dairy cows alone account for a third of all human-generated methane emissions. Cultivating rice, which makes up one-fifth of the daily calories for 2.4 billion people, emits as much carbon as Germany and Japan combined. Food cold chains, the systems used to keep, transport and distribute fresh and frozen food from where it is grown or extracted to the end

OPPOSITE *Sustainable practices in rice cultivation can reduce water use by up to 20% and cut methane emissions by up to 50%.*

RIGHT *Options for reducing methane from cattle and dairy cows include alternative feeds, reducing food loss and waste, and cutting production.*

Vladimir Mulder/Shutterstock.com

consumer, create 1% of global GHG emissions, a percentage forecast to rise as food cold chains are developed in low- and middle-income countries without regulation. Climate change resulting from higher emissions, with an increased risk of severe weather, is a threat to global food security, defined by the Organisation for Economic Co-operation and Development (OECD) as everyone always having 'the physical, economic and social access to enough food of good quality for a healthy and active life'. Food production, therefore, not only needs to adapt to climate change, it must also reduce its GHG emissions.

Simultaneously, feeding the world sustainably requires billions of people to alter their behaviour. Energy-intensive animal protein diets, for example, are ultimately unsustainable. Existing alternatives include expanding the production of edible seaweed and insects, while laboratory-produced meat is already on the market. Reducing food waste is critical too. Every year 1.3 billion tonnes of food are wasted, the equivalent of around one-third of the world's annual food production. Cutting food waste by a quarter could feed 500 million people. The Netherlands, the world's second-largest exporter of agricultural produce by volume, has become the first European country to promise to cut food waste by half by 2030.

Meeting the goal of sufficient sustainably produced food securely and safely supplied to a growing world population requires global collaboration, with every international organisation, national government and local

Alistair Berg/Photodisc via Getty Images

LEFT AND OPPOSITE
Emerging technologies can help to meet the goal of sufficient, sustainably produced food securely and safely supplied to a growing world population.

Zapp2Photo/Shutterstock.com

community playing their part. Better information, education and training will assist individuals and organisations in making better decisions. Emerging technologies can help. Blockchain, for instance (see page 114), can be used to improve the traceability of food supply chains. Genetic modification can make food safer. Urban farming in combination with Data-centric Engineering (see page 189) can shorten supply chains, enhance nutritional content and improve traceability. Fraud can be prevented by 'fingerprinting' food using stable isotope technology. Smart technology applied in food factories can increase efficiency and traceability. Satellites and drones can identify and warn about crop pests.

In many of these areas, from the safer production of food to educating more engineers globally to devise improved methods of delivering clean water to people, the Foundation is helping to achieve progress through the support it gives to initiatives all over the world.

SAFE SUSTAINABLE FOOD

As mentioned above, edible seaweed is a viable alternative food source, and the Foundation has been leading the way in promoting its potential as one way of feeding the world. For millions of people, edible seaweed is a traditional part of their national cuisines; in South Korea and Japan, for example, it makes up 10% of people's diets. Commercial seaweed cultivation is the fastest growing sector in the food world, worth US$9 billion annually, with global production reaching 30 million tonnes.

Most seaweed cultivation takes place in Asia, beyond which the algae's wider potential has been largely unrecognised. According to Wageningen University, cultivating just 2% of the ocean with seaweed could provide enough protein to feed 12 billion people. As well as a sustainable source of protein, seaweed needs only sunshine and water to grow, giving it an immediate environmental advantage over water- and chemical-intensive land-grown crops. Its potential as an energy source has been known for many years, with its residue capable of being converted into various forms of energy, including biogas and ethanol. Research in Australia suggests adding a certain type of seaweed to the diet of cows can reduce their methane emissions by as much as 99%. It also yields iodine, produces biomaterials as an alternative to plastic and helps to capture GHG emissions as a carbon sink. Although new projects have recently been initiated beyond Asia in Europe, the Americas and Oceania, they are taking place in isolation, expertise is limited and the industry is largely unregulated.

In 2016, discussions between the Foundation's Chief Executive, Richard Clegg, and Vincent Doumeizel, LR's Vice-President for Food, Beverages and Sustainability, and later the Foundation's Food Programme Director, led the Foundation to award a grant to Wageningen University in the Netherlands, the world's leading food sciences institution, to develop technical standards for the safe production of food and animal feed from marine plants. As part of this initiative, the Safe Production of Marine Plants and Use of Ocean Space, the university considered how to maintain the safety of the oceans as they become increasingly crowded with multiple renewable energy and aquaculture projects and fishing. Its work helped to allay concerns from offshore windfarm operators about proposals for growing seaweed in the space between structures.

shankar s. (CC BY 2.0) via Flickr

ABOVE *Seaweed for sale at Luang Prabang, Laos. Seaweed, like edible insects, is a traditional part of several national cuisines.*

OVERLEAF *Wageningen University in the Netherlands has helped to allay concerns from offshore windfarm operators about proposals for growing seaweed in the spaces between structures.*

Jesse De Meulenaere on Unsplash

Chris Hellier/Alamy Stock Photo

The Wageningen project also considered the possibility of scaling up seaweed production; scientists estimated that a seaweed field the size of the Netherlands could supply enough protein to feed the whole of Europe.

The project later won EU funding of €20 million as part of the EU's Blue Growth initiative Horizon 2020. Five pilots are currently underway, which the Foundation is helping to verify. Through Vincent Doumeizel, a tireless promoter of the global benefits of seaweed, the Foundation was instrumental in building a global coalition including the Food and Agriculture Organization (FAO) and the UN Global Compact's Action Platform for Sustainable Ocean Business. Doumeizel developed the Seaweed Manifesto, originally the brainchild of Dr Ruth Boumphrey, the Foundation's Director of Research (and successor to Richard Clegg as the Foundation's Chief Executive), in collaboration with partners from the private and public sectors, research institutions and UN agencies. Seaweed Revolution – A Manifesto for a Sustainable Future was launched in June 2020. It set out the opportunities presented by the commercial cultivation of seaweed, the barriers limiting its potential, and a framework for the responsible development of the industry.

The Foundation and the UN Global Compact followed this up in March 2021 by launching the first global platform for seaweed stakeholders, the Safe Seaweed Coalition, led by French research institute CNRS. In a fragmented international industry, the Coalition has succeeded in using food safety to bring together the various parties involved, from small farmers to global businesses, from research institutes to intergovernmental organisations, all working to realise seaweed's potential and to assure its safety, to accelerate change, attract investors and scale up this promising industry in a responsible way. In early 2022, Doumeizel published a book, also called *The Seaweed Revolution*, which is set to become the definitive work of reference on seaweed.

OPPOSITE *The Safe Seaweed Coalition's work includes a project to secure the sustainability and safety of the local seaweed industry in Madagascar.*

The Coalition's work concentrates on consumer, environmental and operational safety. It now has more than 800 members and has funded 15 research projects. These include projects to introduce kelp farming on a commercial scale in Australia, secure the sustainability and safety of the local seaweed industry in Madagascar, and create seaweed-based packaging in the UK. In Namibia, a major farming initiative has the capacity to absorb emissions equivalent to the annual output of the Netherlands. One Coalition partner, the World Bank, is funding the development of industry standards for Southeast Asia; and the Coalition's advice is helping the FAO formulate the first global food safety regulations governing seaweed. The UN Global Compact is incorporating the Coalition's work within its global food strategy. Seaweed's capacity to soak up GHG emissions was also highlighted at COP26.

Looking to the future, other nutritional options include edible insects and laboratory-produced meat. Protein-rich and sustainable, edible insects are already eaten by 2 billion people as part of their daily diets. They are a crucial ingredient in future diets, producing as much protein as poultry,

James Charoenkrung/stockphototrends/Thinkstock

RIGHT *In December 2020 a cultured meat, Chicken Bites, made by the US company Eat Just, was approved for sale by the Singapore Food Agency.*

OPPOSITE *Edible insects are already eaten by 2 billion people as part of their daily diets.*

Eat Just/Business Wire

beef and pork, but requiring half the energy, one-third of the water and 25 times less land than conventional meat. Per tonne, they emit far less GHG than beef or poultry. Expanding their consumption requires regulation and a change in perception in parts of the world where they have never been seen as a foodstuff. In the EU, they are now covered by the Novel Food Directive, introduced in 2018. Insects are also a sustainable alternative for animal feed compared with fishmeal and soya beans.

While there is an established market for edible insects, laboratory-produced meat is still in its infancy. Animal stem cells are placed inside a nutrient-rich fluid and grown in a bioreactor. The multiplying cells, divided into muscle and fat, are assembled into products, such as burgers, nuggets, dumplings and steaks. Cultured meat is more sustainable than traditionally produced meat, requiring virtually no land and using 90% less water. However, its production is costly in energy consumption, underlining the need to move to zero-carbon alternatives, another example of the interrelated and often unintended consequences of tackling climate change. There is also some concern over its safety, including the growth factors added to the stem cells, which include hormones, and the need for absolute sterility in production areas.

The engineering costs have fallen rapidly, and in December 2020 cultured meat was approved for sale by a regulatory authority for the first time. 'Chicken Bites', made by the US company Eat Just, were approved by the Singapore Food Agency. While many other companies are developing cultivated chicken, beef and pork, cultured meat will remain more expensive than the natural product until manufactured in significant volume.

ASSURING FOOD SAFETY

Research by the Foundation's Evidence and Insight Centre revealed the variability of evidence relating to food safety, aquaculture and traceability, and the absence of monitoring and evaluation in many fields. Food safety is a paramount concern, not only for food producers and regulatory organisations, but also for the public. A recent UK survey showed that the most important reason people are persuaded to try alternatives is assurance over safety. More than a third of respondents were deterred by food safety concerns from trying cultured meat and more than a quarter from trying edible insects. LRQA (formerly LR's quality assurance division, and now an independent entity) helps aquaculture businesses to meet industry standards, giving consumers confidence that producers are minimising the environmental and social impact of their activities.

The Foundation's *Foresight Review on Food Safety*, published in 2019, gathered evidence from academics, food companies and others from all over the world. The review made a series of recommendations for improving global

.shock/iStock/Getty Images Plus

LEFT *The issue of food safety is hugely important for food producers, regulatory organisations, and the public.*

Ruben M Ramos/Shutterstock

food safety based on education and training, traceability and exploiting food from the ocean. The Foundation is funding an FAO programme to assess food safety educational capacity and needs in East Africa and in the Caribbean. In Africa, foodborne illness kills some 137,000 people every year, while in the Caribbean foodborne disease is four times as prevalent as in Europe. Part of the problem stems from the lack of training for workers in the food industry. The programme should deliver undergraduate food safety educational curricula, tailored for the specific needs of each region. By raising standards, competence and expertise, the project will reduce sickness and death and boost agriculture and tourism in local economies.

Food safety was one of the key themes appearing in the results of 2019's pioneering World Risk Poll (see page 249). The poll carried out some 150,000 interviews in 142 countries, including many places where little reliable data existed, raising people's concerns for the first time. The results confirmed the importance of food safety for billions of people. Some 60% were concerned about the safety of the food they eat, and 51% about the safety of the water they drink. And 17% had personally experienced or knew someone who had experienced serious harm from eating food in the previous two years. Yet often, the anxiety people expressed about the safety of their food and water was much higher than the actual risk of harm, emphasising the importance of getting across the right information. The FAO welcomed the results, which for the first time offered a global understanding of how people viewed food safety, allowing effective action to allay anxieties.

The results of the 2019 World Risk Poll confirmed the importance of food safety for billions of people.

OPPOSITE *A Foundation-funded FAO programme should produce more food safety professionals with the right skills to make a difference in the Caribbean and East Africa.*

RIGHT *The World Risk Poll showed that 60% of people worldwide are worried about the food they eat.*

Mangostar/Shutterstock.com

SAFER FOOD THROUGH TECHNOLOGY

One of the options highlighted in the *Foresight Review on Food Safety* was the application of blockchain technology, which combines 'the openness of the internet with the security of cryptography to give a faster, safer way to verify information'. It is becoming invaluable for improving food traceability, assuring supply chains and preventing food fraud. As a decentralised register, blockchain works because the data is transparent and unchangeable. It allows different parties to record and share data securely. Every addition to the register can be traced back to its originator and there is no risk of the data being manipulated. LRQA is the leading member of SecQuAL, a UK consortium that aims to use data and blockchain to reduce food waste and improve food traceability; other members of the group include IBM Food Trust, listed food company Cranswick and the UK's Food Standards Agency.

RIGHT *The Digital Sandwich project in the UK involves a consortium of UK universities, technology, food and manufacturing firms to 'irrefutably' track all components of a sandwich with the help of the Internet of Things, blockchain and artificial intelligence.*

Suzan.P/Shutterstock.com

Projects supported by the Foundation are helping to make food and water safer. Invisible nanoscale chemical tagging, which assists the traceability of food supplies, is one of the ideas to emerge from the Foundation-funded nanotechnology project led by Southampton University (see Chapter 4). Other applications of nanotechnology in this field include nanobiosensors capable of detecting contaminants in food; and fine nanotech filters that can remove a wide range of pollutants – from chemical effluents to bacteria – from water. With significant losses of water attributable to leaks (globally, a third of water utilities claim leakages cause a loss of as much as 40% of clean water) digital sensors and machine learning can be combined to monitor water networks continuously online, detecting leaks more speedily and recording them more accurately.

The Foundation also supports the work of the UK's Royal Academy of Engineering, whose drive to expand and enhance engineering education globally will contribute to solutions for delivering better drinking water to more people. With 2 billion people without access to safe drinking water, these initiatives are invaluable.

Roger Dale Pleis/Shutterstock.com

LEFT *Throughout the world leakages are reportedly causing the loss of 40% of clean water supplies.*

OPPOSITE *Developing engineering education globally will contribute to solutions for delivering better drinking water to more people, such as desalination plants.*

Andy Sotiriou/Photodisc via Getty Images

BETTER WATER FOR THE PEOPLE OF KATHMANDU

In Kathmandu, Nepal, there are frequent complaints about the quality of the water supply, but there is often insufficient information to resolve them. Thanks to a multi-disciplinary collaboration between the Singapore-based Institute for the Public Understanding of Risk (IPUR), Nepal Engineering College and Imperial College, London, with funding from Lloyd's Register Foundation, an app – Networking Water Data – has been developed to help local people collect the data to support their complaints. In addition, a team led by Dr Olivia Jensen from IPUR has delivered simple kits to local households to test water quality, which is usually tested only as it leaves the treatment works. For Dr Jensen, the project has proved the value of citizen science in engaging people and collecting valuable information:

> 'We're arming the people of Kathmandu with the tools to back up their demands so they can make improvements to both supply and quality.'

Mickey Lee Mediamixer.co.uk/Lloyd's Register Foundation

LEFT AND OPPOSITE
'Access to a steady supply of clean water is just a pipe dream for a million people living in Kathmandu,' says Dr Olivia Jensen, IPUR. 'Water flows to each household for only a few hours … and even when the taps do run, the water coming out of them can be unsafe to drink.'

Nabincha/Shutterstock

Lee Junda on Unsplash

CHAPTER 3:
PREPARING FOR AN UNCERTAIN FUTURE

We are in a time of transition.

LEFT *Communities must become better prepared and resilient to deal with natural disasters and other shocks.*

In 2021, the Lloyd's Register Foundation's *Foresight Review on the Future of Regulatory Systems* outlined that, compared with more settled times, today's problems are:

> 'Vastly different in their scale, their inter-connectivity and their ability to accelerate at pace. They result in deep uncertainty, where the significant lack of knowledge means that outcomes cannot be confidently predicted.'

The instability created by climate change and the disruption created by the accelerating development of a digital future make the world a more uncertain place. The Covid-19 pandemic highlighted the impact of sudden, unexpected global events. The world was unprepared. Governments struggled to respond. Millions have died. Millions more have endured economic hardship and social deprivation. Keeping people safe from a virulently contagious disease became critical to avoid complete economic and social breakdown.

Sipa US/Alamy Stock Photo

ABOVE AND RIGHT
In 2020 the Covid-19 pandemic demonstrated how ill-prepared the world was in dealing with a global pandemic. The UK's National Covid Memorial Wall on the Albert Embankment next to St Thomas's Hospital (above); drive-through testing (right).


MexChriss/Shutterstock.com

Sunguk Kim on Unsplash

Communities must become better prepared for the unexpected. The infrastructure supporting our daily lives must be able to withstand sudden shocks. Safety must be a paramount consideration. That is why resilience is a recurring theme throughout this chapter, whether for people, structures or systems. In the Foundation's *Foresight Review of Resilience Engineering*, published in 2015, the term is defined as 'the emergent property or attributes that some systems have which allows them to withstand, respond and/or adapt to a vast range of disruptive events by preserving and even enhancing critical functionality.'

Lloyd's Register Foundation's support for resilience engineering has done much to further the concept and raise awareness of its advantages. It is helping to shape views on how we can make future infrastructure robust enough to survive the unexpected. It is funding organisations researching how to ensure the safety of the complex systems created by advancing technologies. And it promotes the benefits of making safety an integral part of the design of any infrastructure, structure or system.

OPPOSITE *When the Golden Gate Bridge opened in 1937, there was less understanding of seismic risk and reinforcement. Retrofit works to bring it up to today's standards are ongoing. A bridge built today would be engineered for resilience.*

SEARCH AND RESCUE RESPONSE DURING A PANDEMIC

During the Covid-19 pandemic it was essential that search and rescue organisations worldwide continued operating safely. With more than 320,000 lives lost every year through drowning, these organisations provide a vital service. Yet saving lives on the water during the pandemic posed a risk to the lives of the rescuers. In response, with funding from Lloyd's Register Foundation, the International Maritime Rescue Federation (IMRF) produced its *Pandemic Response Guidance for Maritime Search and Rescue Organisations* in 2021. Recognising that Covid-19 will not be the world's last pandemic, the IMRF ensured that its guidance could be applied to future health emergencies.

'This guidance brings together all the knowledge and experience of our international membership. It began life as guidance designed specifically to meet the SAR operational challenges faced in the current global pandemic, but, with the help of Lloyd's Register Foundation, we have been able to develop it further for use as a basis for operational planning and response in any future pandemics or major health emergencies.'

Theresa Crossley, Chief Executive, IMRF

charl898/Shutterstock.com

ABOVE *The COVID-19 pandemic presents very serious challenges to search and rescue crews, as they care for those they rescue and protect their own well-being.*

lax15las/Shutterstock.com

ABOVE *The 2011 tsunami flooded a huge inland area of Japan's Honshu Island.*

RIGHT *Checking radiation levels at the Fukushima nuclear plant in April 2011 before spraying an anti-scattering agent to prevent the spread of radioactive materials.*

TEPCO

COMMUNITY RESILIENCE

On 11 March 2011, a major earthquake with a magnitude of 9.1 off the north-east coast of Japan's Honshu Island set off a devastating tsunami. It flooded a huge inland area, hit the coastal ports and towns of Tohoku, destroyed or damaged more than a million buildings, and took the lives of nearly 20,000 people. The four nuclear power stations in the region withstood the earthquake but proved vulnerable to the tsunami. The worst affected were three reactors at the Fukushima plant where backup generators and heat exchangers failed, making it impossible to cool the reactors properly. All three cores largely melted over the next three days. It caused a major nuclear accident, releasing significant radioactivity into the atmosphere. More than 100,000 people had to move as a precaution and many have never returned. The disaster showed how important it is for systems to be sufficiently resilient to ensure safety. It also demonstrated how people rather than systems are often more capable in the face of adversity.

This lesson was illustrated movingly in a talk some years later by Atsufumi Yoshizawa, one of the Fukushima engineers who volunteered to shut down the plant. He ended his presentation with a photo of himself in his hazmat suit: colleagues at the plant took turns photographing each other and sending the pictures to their loved ones because they were certain they would not survive. But they did, and they succeeded in their mission. His point was that people are the ultimate source of resilience.

Eighteen months later, on 29 October 2012, Hurricane Sandy hit New York. Over 48 hours, the hurricane destroyed some 300 homes, left much of the city without power, damaged critical infrastructure and made it almost impossible for many people to obtain food, drinking water, healthcare and other services. There were 44 deaths, damage and economic loss of approximately US$19 billion and the temporary displacement of thousands of people.

Michael Bruno was an academic teaching naval architecture and ocean engineering at the Stevens Institute of Technology in Hoboken, New Jersey. 'Everything,' he said, 'changed after Hurricane Sandy.' At the time, he had no knowledge of the limited programme devised to strengthen resilience in the aftermath of Fukushima by the University of Tokyo, but the devastation of Hurricane Sandy brought him to the same conclusion. Lloyd's Register Foundation sponsored an undergraduate scholarship at the Institute, and Bruno remembered a conversation with Richard Clegg, the Foundation's Chief Executive:

> 'I remember we were discussing the ability of certain areas of the New York metropolitan region to bounce back while some other areas, and even different companies and agencies, were not able to recover very quickly. And in the course of the conversation, I remember thinking out loud, is it possible to engineer resilience into these systems, could there be such a thing as resilience engineering? And that really resonated with the Foundation.'


Danielle Austen

LEFT *Michael Bruno: 'Everything changed after Hurricane Sandy.'*


NASA/Goddard

ABOVE *A satellite view of Hurricane Sandy at noon on 28 October 2012, off the southeastern United States. When it made landfall in New Jersey, it extended about 900 miles (1,500km) from end to end.*

ABOVE *The New York City government offers incentives to install green roofs that help absorb stormwater and prevent street-level flooding.*

Could infrastructure be designed from the outset to be more resilient in the face of disruption?

The Foundation encouraged Bruno to develop his ideas and sponsored an international research conference with experts from around the world in 2013. Bruno notes that academia initially regarded the idea as 'not quite the thing', just as environmental engineering had been in the 1970s. However, just as that discipline became a standard programme in engineering universities, resilience engineering has made the same journey. It brings together the technical with the social, with an emphasis on community resilience, with all the implications that has for social equity and education. Since systems completely resilient to disruption are impossible to create, ultimately, as the Fukushima disaster highlighted, resilience depends on the people who design, build, operate and use them.

The research that started soon after Hurricane Sandy, backed by the Foundation, had a pronounced impact on the way communities adapted to future storms. Outreach and education have raised awareness that major storms will become more frequent. The efforts of Lloyd's Register Foundation, the Rockefeller Foundation and other similar bodies helped connect communities, cities, technical bodies, engineering firms and academic institutions worldwide. Knowledge is shared and lessons are learned more quickly. For example, many neighbourhoods in and around New York adopted the flood-control method widely used in low-lying countries like the Netherlands, creating special ponds to capture, store and release excess water. 'I have just been astounded,' reflected Bruno, 'over the last five to ten years about how much work has gone on about adaptation in these communities at high risk.'

Encouraging communities to be more resilient becomes more urgent with the acceleration of climate change. 'I don't think those of us working in this field 20 years ago,' said Bruno, 'ever thought we would see dramatic evidence of sea-level rise.' The digital and data revolution makes it possible to model and predict weather events in a way unimaginable a decade ago. Thanks to big data, coupled with greater computer power, it is possible to simulate the impact of past events on today's environment. This provides decision-makers with invaluable insights and helps to promote greater public understanding.

Arik Karagyozyan/Stockimo/Alamy Stock Photo

LEFT *Lemon Creek is part of the Staten Island Bluebelt, a New York City programme that preserves and optimises natural drainage corridors to manage stormwater and reduce flooding.*

The Foundation's backing for the development of resilience engineering stemmed from its mission in safety; its 2015 *Foresight Review of Resilience Engineering* was subtitled 'Designing for the expected and unexpected'. Bruno chaired the panel of experts who contributed to the report. It cited several disruptive events, from the devastation caused along India's eastern coast by Cyclone Phailin in 2013 to the more frequent flooding endured in recent years by many parts of the UK, as examples of their cascading impact on critical infrastructure and vulnerable communities. Once again, it underlined how vital people were in ensuring the ultimate resilience of engineered systems.

The Resilience Shift programme (see page 75) came out of this review, launched with Foundation funding in 2016. The name indicated the programme's aim of shifting thinking to embrace the application worldwide of resilience engineering to ensure continuity in the face of disruption to systems and services vital to human life. For Bruno:

> 'It has been very satisfying to see that resilience engineering has been adopted and accepted as part of the language in broad engineering and planning disciplines. A word that was not really in most people's vocabulary 15 years ago is now widespread. You now have government agencies around the world with the word resilience or resiliency in their title. This wasn't present 15 years ago. That's a pretty remarkable thing to see.'

Barry Batchelor/PA Images/Alamy Stock Photo

ABOVE *Tewkesbury in Gloucestershire was the worst affected part of the UK when the floods hit in July 2007 after double the average rain fell between May and July. It was some of the worst flooding ever recorded in Britain.*

RIGHT *Flooding in the city of York in December 2015 following heavy rain.*

PhilMacDPhoto/Shutterstock

Reyes de Aspe/Lloyd's Register Group

ABOVE, RIGHT AND OVERLEAF *Ensuring that infrastructure is well prepared for the unexpected and can withstand sudden shocks is vital, from wind farms to bridges and transport networks.*

Ameya Mathkar/Lloyd's Register Group

RESILIENT INFRASTRUCTURE

Just as making sure people are well prepared for the unexpected is vital, so too is ensuring that existing infrastructure, from wind farms and nuclear power stations to bridges and transport networks, can withstand sudden shocks. This is one of the major global challenges identified by the Foundation. It is particularly important in a time of climate change when most of the world's existing infrastructure was designed to cope with a more benign climate.

The Foundation is addressing the challenge through several projects. It has helped promote the concept of Data-centricEengineering in a digital world (see Chapter 4) and one of the challenges within the Alan Turing Institute-Lloyd's Register Foundation programme, is using Data-centric Engineering to create more resilient infrastructure as part of a safer engineered world. The Foundation also identified in its *Foresight Review of Cyber Security for the Industrial IoT – Enabling safer more resilient infrastructures* (2020) the need to insulate critical infrastructure (the Internet of Things, see page 222) from the threat of cyber-attacks. Currently, in partnership with The Welding Institute (TWI), the Foundation is involved in a project, Infrastructure 2040, gathering expert advice and information on planning the infrastructure of the future.

Structural integrity aims to prevent failure by minimising risk, maximising safety and assuring the basic function of every structure. It combines good design with effective maintenance over the structure's predicted lifespan. It ensures that any structure, once complete, performs as expected under normal circumstances and remains safe under more extreme conditions, preventing catastrophic failure. The malfunction of any one component should not result in the failure of the entire structure. It should avoid the most common causes of failure, such as poor design, inappropriate or inferior quality materials, or faults in manufacturing or construction.

Any accurate assessment of structural integrity must consider the impact of new manufacturing processes and materials. This can be achieved through big data and digital technology. Digital sensors provide the constant monitoring needed to ensure the safety of structural assets with a much longer lifespan than in the past. Data science helps to analyse the complex information they supply. Understanding advancing technology is crucial for devising the best protection against the failure of structural components.

Gerard Gaal/Lloyd's Register Group

One area of vulnerability is the increasingly interdependent relationship between today's infrastructure networks, from water and power to telecommunications and transport. The failure of any one of these networks may have a cascading effect, knocking out others, damaging social well-being, national security and economic prosperity. As well as assuring the integrity of any one structure, it is therefore essential to understand how one relates to another.

Much of today's critical infrastructure was completed before climate change was widely acknowledged. It was designed to cope with local conditions, with occasional storms or floods where any damage could usually be repaired. With a warming and less predictable climate, however, once-rare extreme weather events are more frequent and more intense, while rising humidity and higher average temperatures change the way structures perform.

Global warming exposes the limitations of structures built during an era when a predictable climate was taken for granted. In the summer of 2021, soaring temperatures nearing 50°C (122°F), created by the hot air trapped in the heat dome hovering over the Pacific Northwest, caused many homes to overheat, imperilling the lives of their inhabitants. In the same year, higher temperatures were one factor making the 300-m high SEG Plaza skyscraper in Shenzhen, China, shake. In the UK, more severe floods are becoming a regular part of the climate, highlighting not only inadequate flood defences but also

RIGHT *Completed in 1982, the Thames Barrier spans 520m across the River Thames, and it protects 48 sq. miles (125 sq. km) of central London from flooding caused by tidal surges. The question is whether the structure can continue to protect the capital against increased risk of flooding caused by climate change.*

Maciej Wolaniecki/Lloyd's Register Group

bingfengwu/iStock/Getty Images Plus

LEFT *In 2021, high temperatures were one factor that caused the 300-m high SEG Plaza skyscraper in Shenzhen, China, to shake.*

BELOW *In the summer of the same year, with temperatures nearing 50°C (122°F), Canadians made use of special cooling centres to take a break from overheated homes and offices.*

Margarita Young/Shutterstock

the dangers of development on traditional floodplains. At the same time, some ancient settlements are predicted to become uninhabitable by the end of the 21st century. In Brazil, flooding has repeatedly displaced a community of indigenous Pataxó and Pataxó Hãhãhãe people from their village. Buildings in coastal areas are particularly susceptible to rising sea levels since salt water accelerates rusting and a saltier water table can harm building foundations. In Indonesia, the Institute for the Public Understanding of Risk has been working on a project with authorities and World Bank to evolve an integrated

Mdoubrava/iStock/Getty Images Plus

urban water management approach in Greater Jakarta. The area has severe water risks including flooding, sanitation, water supply and water quality. The government is relocating the capital to higher ground away from Jakarta because flooding is causing the city to sink into the Java Sea.

A major concern is the effect of a warmer, wetter climate on structures incorporating concrete reinforced with steel. When wet, steel will rust and expand, fracturing the concrete and weakening the structure. Rising greenhouse gas emissions cause an increase in carbonation, which weakens concrete and increases the chance of steel corroding. Some observers believe carbonation played a role in the collapse of a Miami apartment block in the summer of 2021, which killed 98 people.

ABOVE *A warmer, wetter climate could cause the steel in reinforced concrete to rust and expand, fracturing the concrete and weakening the structure.*

THE NATIONAL STRUCTURAL INTEGRITY RESEARCH CENTRE

Given the susceptibility of critical infrastructure globally to a growing number of external factors, increasing the pool of knowledge through further research is vital. One of the UK's foremost engineering institutions, TWI, has been at the forefront of this challenge. With many of its members operating safety-critical infrastructure in sectors such as aviation and shipping, highways and offshore oil and gas, TWI embarked on an ambitious programme to create a body of postgraduate researchers investigating how best to ensure the structural integrity of such infrastructure.

At the heart of this programme was a new multi-million-pound National Structural Integrity Research Centre (NSIRC), a global research hub housed in purpose-built accommodation just outside Cambridge, UK. Founder sponsors were the international energy company BP and the Foundation. More than 30 universities from across the world have become involved, attracted by the aim of carrying out research within an industrial environment. This collaboration is fundamental to generating knowledge and promoting global good practice.

Given the susceptibility of critical infrastructure globally to a growing number of external factors, increasing the pool of knowledge through further research is vital.

Since the opening of the NSIRC, the Foundation's initial funding of £15 million has helped generate activity relating to structural integrity worth around £500 million from fundamental research to practical application. The Foundation, said its Director of Technologies Dr Jan Przydatek, is training 'brilliant people who go out into industry and advance safety in the world through the work they do'. Nearly half of them are women, helping to go some way to redress the gender imbalance in the engineering world. Many students also come to the Centre from low- and middle-income countries who return home upon completing their doctorates and build up local capability. With much of the current infrastructure development worldwide taking place in these nations, they make a vital contribution to their national expertise in structural integrity. The programme has proved so successful that TWI and the Foundation are investigating how the NSIRC model can be extended out to low- and middle-income countries.

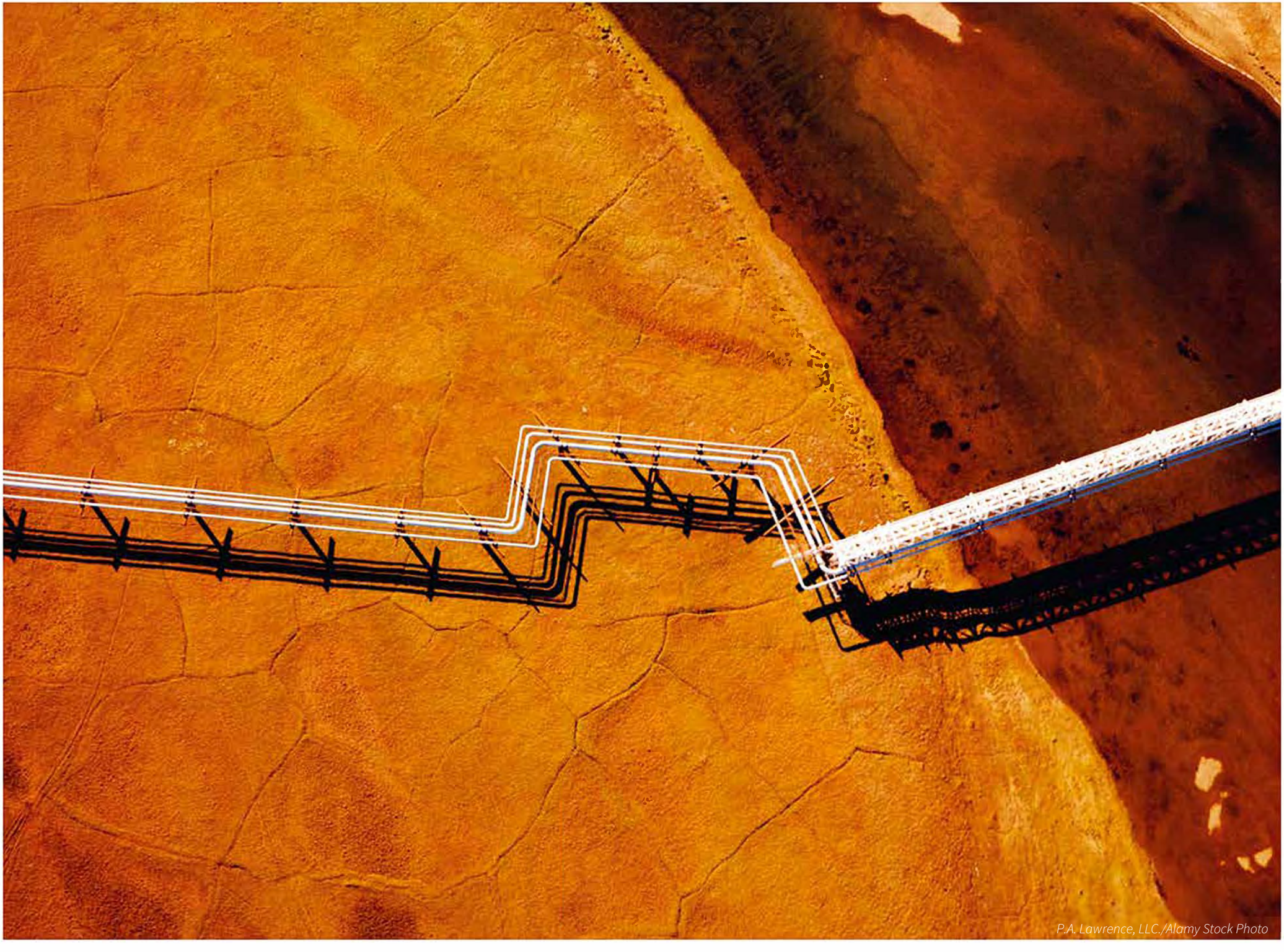
Two examples illustrate how the industrial focus of the NSIRC's research helps to accelerate its practical application. TWI's partners have trialled sensors capable of operating in temperatures of up to 250°C (482°F) for use in inspecting structures such as long-range pipelines. Following the successful development of this type of sensor by an NSIRC student under laboratory conditions, when a crack was detected in a component at a nuclear power station, the sensor was used to monitor the crack while the plant continued to operate. Without this device, the plant may have had to shut down, depleting the UK's available energy by 4%.

NSIRC research has also helped shape national and international standards on the structural integrity of safety-critical infrastructure. This has been strongly supported by LR, one of TWI's founding partners, because of its contribution to safety assurance. This pioneering research made possible a more flexible, less conservative approach towards standards.

TWI Ltd

ABOVE *PhD student Laura Vivar joined NSIRC in 2014 and Jazeel Chukkan joined shortly after. Nearly half of the PhD students are women.*

OVERLEAF *An example of the industrial focus of the NSIRC's research is the trial of sensors capable of operating in temperatures of up to 250°C (482°F) for use in inspecting structures such as long-range pipelines.*



P.A. Lawrence, LLC./Alamy Stock Photo

SAFER COMPLEX SYSTEMS

Most people are happily ignorant of the complexity of the systems that underpin the critical infrastructure we depend on. This surfaces only occasionally, for example, during the Covid-19 pandemic when complex global supply networks were disrupted. Although interlinked systems, which affect everything we do, are intended to be resilient, they can also fail.

> 'Contemporary technological designs are increasingly tightly coupled and complex, leading to cascading failures and confounding human operators of the system. This points to resiliency, especially to the effects of unexpected and low probability events, as an increasingly important feature to understand, communicate and build into our systems.'
>
> Lloyd's Register Foundation, *Foresight Review on the Public Understanding of Risk*, 2017

The complexity of these systems often makes monitoring their vulnerability difficult for human operators. Engineers not only need to understand these complex socio-technical systems but also how they interact with people. This huge challenge has been taken up by the UK's Royal Academy of Engineering.

apiguide/Shutterstock.com

OPPOSITE *Complex, interlinked systems, which affect everything we do, are intended to be resilient, but they can also fail.*

ThisisEngineering RAEng on Unsplash

ABOVE *The UK's Royal Academy of Engineering has taken up the challenge of understanding complex systems and how they interact with people.*

The Safer Complex Systems project is part of the Royal Academy of Engineering's ambitious Engineering X programme, supported by the Foundation. It aims to work with the diverse community that designs, operates and manages these systems to do better collectively. The programme is global, focusing on governance, education, advocacy and convening communities together. Engineering X commissioned 19 international case studies to help understand complex systems in an unpredictable world. These brought together people from different parts of the world in contrasting sectors to share their experience of complex systems, develop a common language and highlight the key issues.

ENGINEERING X AND COMPLEX SYSTEMS

International case studies included in a review commissioned by Engineering X not only show how diverse complex systems can be, but also provide lessons for similar circumstances. One study carried out by a team at Universidad de los Andes, Colombia, investigated the response of the authorities in Bogotá to the growth in cycling in the city during the Covid-19 pandemic. Other transport networks in comparable crisis situations can learn from the rapid development of the city's cycling network, with its implications for cycling safety and community resilience. In the UK, among other rail-related case studies, Dr Brian Haddock of Network Rail is leading a group investigating how to mitigate weather-related disruption of the rail network, which will benefit operators of other similar complex systems, such as supply chains, energy and data networks. Kindling, a US-based non-profit supporting global fire safety, is undertaking a comparison of the incidence of fire risk in informal urban settlements in Dhaka and Cape Town. It is tracing the interaction between underlying social, political and economic infrastructure systems, identifying key principles and approaches for use in studying fire and other human-made risks in similar settlements in other major cities to help reduce fire risk.

Some of the studies take a more general approach. One of these is conducted by Field Ready, a non-profit that specialises in humanitarian aid and disaster relief, which aims to learn from the experience of global humanitarian supply chains during the pandemic to minimise future disruption. Another team is investigating at what point existing ideas for managing risk in complex systems become obsolete and what should replace them before systems fail.

Although the contexts are varied, everyone has gained a better understanding of complex systems by learning from each other, allowing better understanding of their own application.

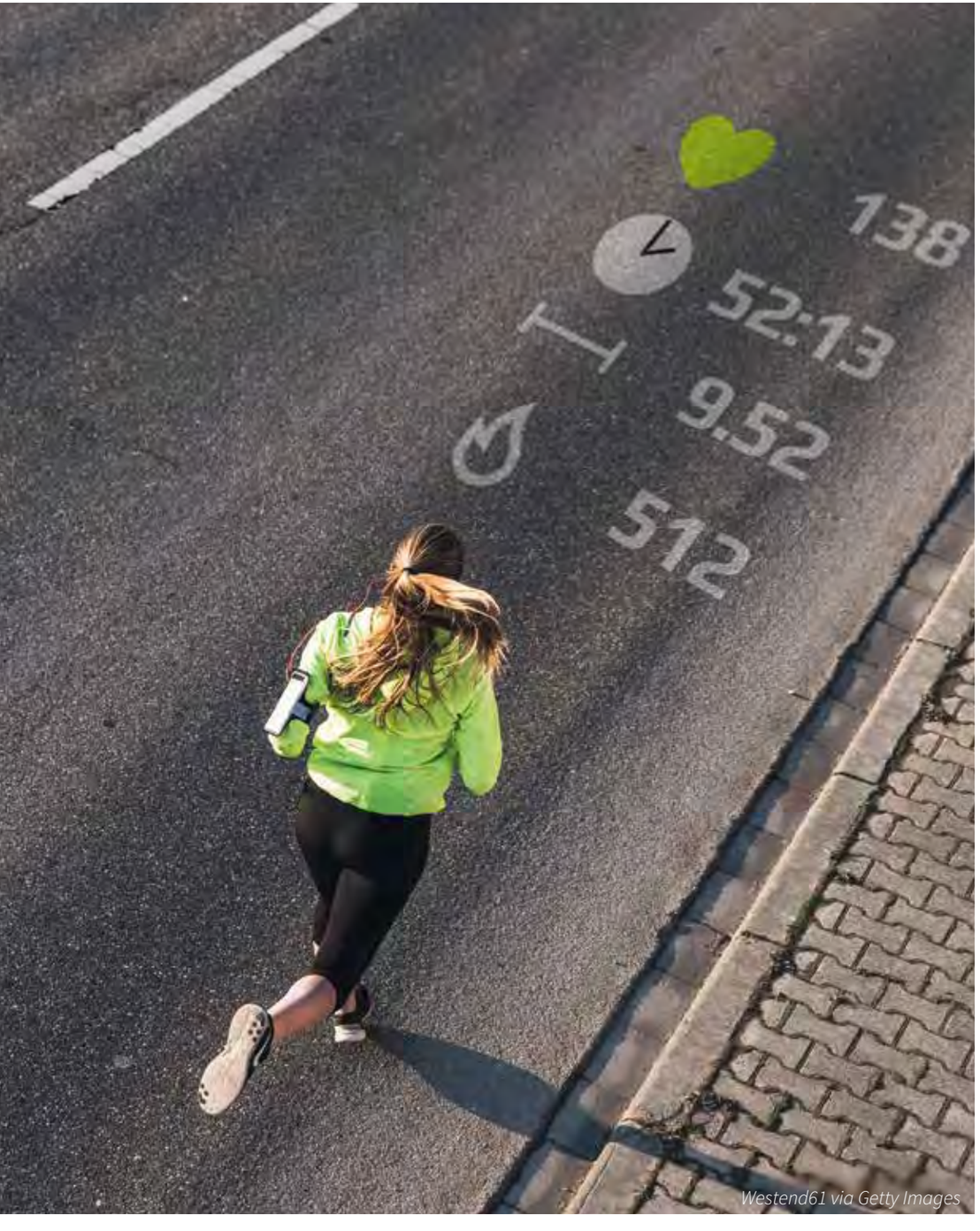
Charles HB Mercer/Shutterstock

Julien Harneis (CC BY-SA 2.0) via Flickr

photorawjpg/Shutterstock.com

Case studies commissioned by Engineering X included the response of the authorities in Bogotá to the growth in cycling during the Covid-19 pandemic (top), humanitarian aid and disaster relief (above), mitigating weather-related disruption of the UK rail network (above right), and fire risk in informal urban settlements in Dhaka and Cape Town (right).

Gabriel Leonardo Guerrero/Shutterstock



Westend61 via Getty Images

The emphasis of the Safer Complex Systems project is on helping communities better understand how to manage such systems and learn from each other.

Digital systems are particularly challenging. 'The scale and complexity of these networks,' noted Lloyd's Register Foundation's *Foresight Review of Global Safety Evidence* (2018), 'makes risk difficult to predict and difficult to manage once they have manifested themselves. Risks are often unanticipated which makes them even harder to manage.'

One approach to tackling these challenges was the creation in 2016 by the UK government of the PETRAS (Privacy, Ethics, Trust, Reliability, Acceptability and Security) National Centre of Excellence for IoT Systems Cybersecurity. PETRAS brings together a wide range of partners from industry and academia intent on ensuring that the Internet of Things (see page 222) must enhance people's well-being and quality of life without compromising safety and security. The Foundation, with its mission in safety, was one of the funding partners.

Digital systems are prone to cyber-attacks. In 2017, the WannaCry incident involved ransomware attacks on hospitals in Europe and North America, which blocked access to patient records. A Russian attack on the Ukrainian power grid in 2015 left 230,000 people without power for several hours. The 2021 attack on the oil company Saudi Aramco threatened the company's ability to supply 10% of the world with oil.

OPPOSITE *Industry must work to ensure that the Internet of Things enhances well-being and quality of life without compromising safety and security.*

OVERLEAF *In operating complex industries digital systems afford opportunities but they are prone to cyber-attacks.*

Kentaro Sakashita/Thinkstock

The potential for catastrophe is greatest in the most hazardous industries, as Fukushima illustrated. Interconnectivity through smart technology based on standard computer architecture leaves systems vulnerable. It cannot be stressed often enough how their complexity makes it more difficult for human operators to monitor them effectively.

A range of measures can be adopted to make systems more resilient. They need to be strengthened against external attacks. Safety should be an integral part of future designs to minimise vulnerability and systems should be reassessed continuously for risk as they are upgraded. Continuous training for operators is a safeguard against poor decision-making through lack of knowledge.

BELOW *The complexity of the most hazardous industries makes it more difficult for human operators to monitor them effectively.*

Zapp2Photo/Shutterstock.com

DESIGN FOR SAFETY

The disproportionate effect of disruptive events, such as more frequent and more severe storms, can be addressed through design for safety. This was the subject of another *Foresight Review* published by the Foundation in 2018. Taking evidence from global experts, the report highlighted the community benefits of design for safety. The concept complements the concept of resilience engineering. Given the increasing complexity of critical infrastructure and systems, when the failure of one part can lead to the failure of the whole, it makes sense to integrate safety into design from the outset. When people are the ultimate source of resilience in the face of adversity, as pointed out above, it also makes sense to ensure that as many interested parties as possible have a say in what safety means to them.

Design for safety goes beyond the requirements of legislation, regulation and standards; it goes beyond traditional design methods. It takes a holistic approach to understanding the issues influencing safety. It requires collaboration across different disciplines. It is all about 'designing with' rather than 'designing for'. In the emphasis it places on human factors in considering safety in design, it differs from previous approaches, although it has long been understood that design for safety can influence human behaviour. The introduction of the three-point car seat belt by the Swedish car manufacturer Volvo in 1959 is a case in point. Another more recent example is the rebuilding

Banglens/Shutterstock.com

LEFT *The comfort and convenience of the three-point car seat belt developed by Volvo in 1959 showed how design can influence human behaviour.*

RIGHT *Lessons can still be learned from the way humans and technology interact and human behaviour will continue to influence design for safety.*


SeventyFour/Shutterstock.com

in New York that followed Hurricane Sandy in 2012. The US government task force invited a broad range of participants to share their views, from local government and local communities, to experts in design and safety. Giving them all a stake in the project created a shared sense of responsibility and built trust between diverse groups, including people directly affected by the storm and its aftermath, and led to innovative environmental policies for tackling future climate change events.

But implementing design for safety requires further building blocks: a better understanding of how human behaviour, culture and emotions affect safety; the development of guiding principles and practical advice for the concept; global networks for sharing best practice; and improved education and training.

Design for safety can learn lessons from the interaction between humans and technology. Most systems depend as much on the human operator as they do on the technology. Thus, while more complex systems create greater risks, and emerging technologies bring new risks, human behaviour and culture are likely to remain an integral part of the safety equation. Like resilience engineering, design for safety helps control new or unknown risks before they can cause harm.

THE SAFER TRANSFER OF PILOTS AT SEA

While an undue emphasis on technology at the expense of human factors may contribute to poor decisions, innovative, safer technologies, developed through sharing knowledge, can help to reduce risk – provided that any risk is clearly communicated and understood. This approach was central to the Safety Grand Challenges set by the Royal College of Art in association with Lloyd's Register Foundation in 2018. One of the challenges took on the longstanding problem of transferring pilots safely between vessels at sea.

Even in our technological age, pilots still embark or disembark from small boats in all weathers using little more than an unstable rope ladder. One solution, Dynaweb, is made from innovative materials, three times lighter and 10 times stronger than traditional rope ladders; while another, the Cross Lock System ladder rigging, is designed to eliminate human error while enabling pilot and crew to communicate with each other. A prototype, Embark, combining the two has been commercially developed by Helm Innovation.

Helm Innovation Ltd

ABOVE *CEO of Helm Innovation, Madelaine Dowd, and CTO and Lead Design Engineer, Josh Chidwick, look at a prototype design for a pilot ladder based on safety solutions from Royal College of Art students.*

Bloom Productions/DigitalVision via Getty Images

CHAPTER 4:

THE DIGITAL AND DATA REVOLUTION

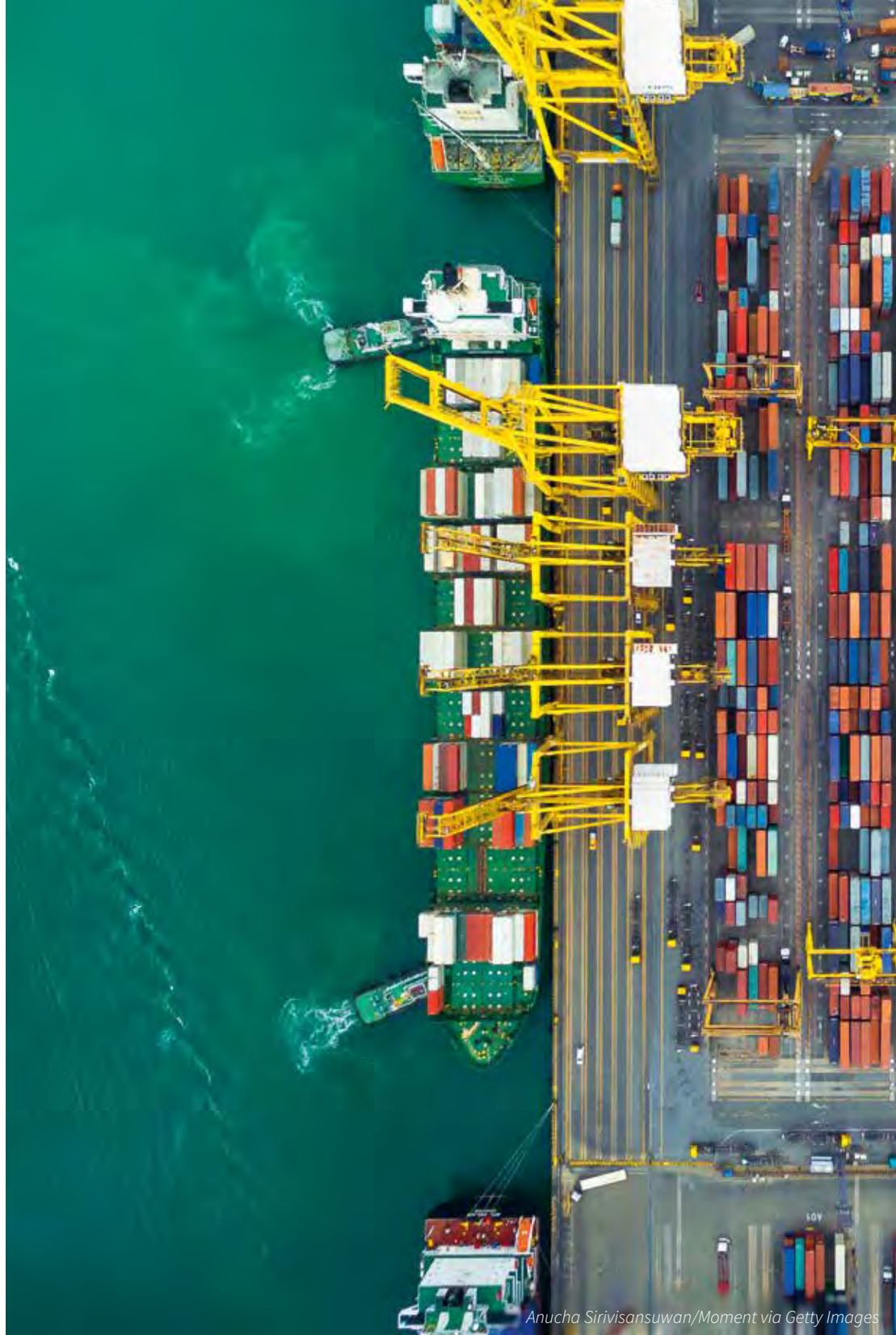
Advances in digital technology and data science bring great opportunities and great challenges.

LEFT *In its* Foresight Review *series, Lloyd's Register Foundation has identified the potential of the digital and data revolution for improving safety across the globe.*

The Internet of Things (IoT) has become part of everyday life. The term was conceived by an employee of the consumer conglomerate Procter and Gamble in 1999 to describe the network connecting objects in the physical world to the digital world. Today, it encompasses everything from home appliances to heavy machinery, production lines to containerships. The world is already filled with tens of billions of smart devices controlling a huge array of systems in almost every part of our daily lives.

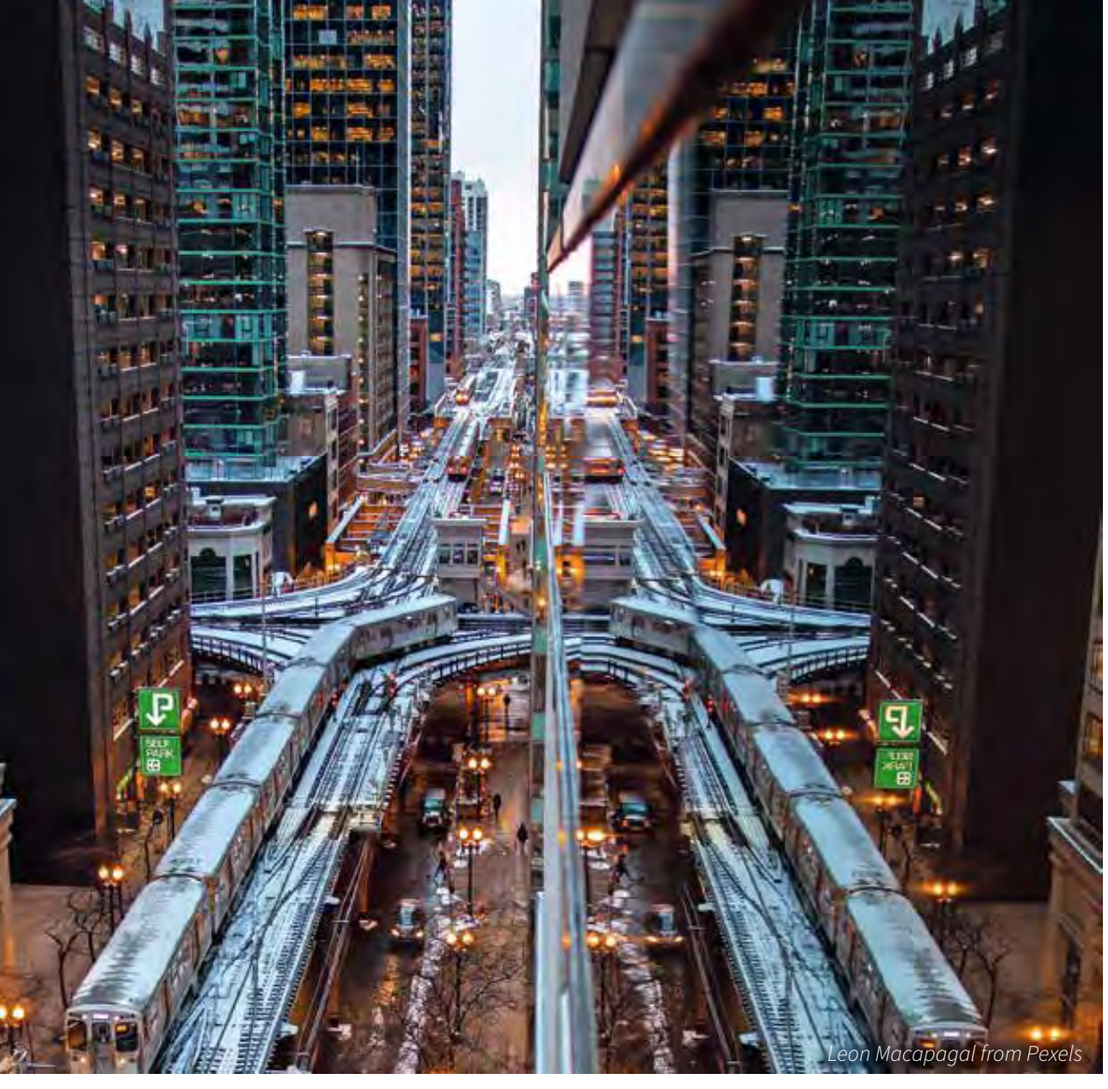
These billions of devices collect vast amounts of data. In 2014, Lloyd's Register Foundation's *Foresight Review of Big Data* gave examples of the scale of data collected by large web companies: Twitter, for example, amounted to 3.5 terabytes (3,500 gigabytes) per year. In 2018, it was estimated that five exabytes (five billion gigabytes) of information flowed through the internet every day; by 2025, the daily amount of data generated globally each day will reach 463 exabytes.

While this massive generation of data raises concerns about its quality, traceability and veracity, it can also yield huge benefits. One of those benefits is making the world a safer place. Digital nanosensors, relaying information in real time, significantly improve the safety of a wide range of structures. Sharing data enhances safety as well as decision-making and drives innovation. Lessons and trends in safety otherwise hidden can be harvested from countless accident records through powerful data analysis.



OPPOSITE *The Internet of Things encompasses everything from home appliances to heavy machinery, production lines to containerships.*

Anucha Sirivisansuwan/Moment via Getty Images



Leon Macapagal from Pexels

ABOVE *Sensors embedded in objects – roads, bridges, trains – feed data to build a 'digital twin'. Using this twin leads to more efficient decision-making, design and maintenance and increased safety.*

OPPOSITE *Using big data analysis it is possible to learn lessons from a mass of archived incident and safety information to help global efforts to improve safety.*

The Foundation identified the potential of this revolution in its *Foresight Review* series, covering the potential of big data and progress in digital technology for improving safety across the globe. The international experts contributing to the Foundation's reviews highlighted how many of these new developments, including big data and nanotechnology, could combine to create innovative approaches to tackling safety. One of the most notable was the advances in Data-centric Engineering with its implications for the safety of engineered structures (see page 189).

BIG DATA FOR SAFETY

All over the world, organisations are analysing big data to help global efforts to improve safety on land, sea and in the air. It is now possible to use data analysis to draw lessons from a mass of archive safety information. Safety data from organisations around the world – such as the World Health Organization (WHO), International Labour Organization (ILO) and the UK's Health and Safety Executive (HSE) – can be collated and analysed to identify strengths and weaknesses. Easier access to different data sources makes it possible to use other information to place safety in a wider context. For instance, many organisations now consider health issues when reviewing safety. Furthermore, cultural differences in attitudes towards safety can also be considered when framing international guidelines.

Clive Postlethwaite/Shutterstock

Launched in 2019, the Discovering Safety project, a partnership between the HSE and the Foundation, uses data analysis to enhance safety. Advances in digital technology made it possible to exploit the potential of HSE's collection of data stretching back 40 years on why accidents happen, a largely untapped resource. HSE's Chief Scientific Adviser and Director of Research, Professor Andrew Curran, had contributed to the Foundation's *Foresight Review on Big Data*, which opened his eyes to the possibility of analysing unstructured data. He believed that relevant data sources from around the world, combined with that of the HSE, could be usefully mined to identify gaps in safety knowledge and contribute towards significant improvements in global occupational health and safety. The outcome would be the creation of a knowledge library of safety data on a scale never seen before. 'We discovered a gold mine,' said Curran:

> 'What Discovering Safety was doing was putting a shop on top of the gold mine where people came and told us what they wanted so we could shape the gold into something they wanted to meet their particular needs. It is now in its third year, and I am very proud that what started as an idea between Richard [Clegg] and myself has developed into something world class, delivering good products with a good chance of becoming sustainable in the long-term.'

Discovering Safety created opportunities to work with innovators adopting novel approaches towards important health and safety issues which would have been difficult for HSE to achieve on its own. Working in association with the Thomas Ashton Institute for Risk and Regulatory Research, the programme developed text mining (the process of deriving quality information from text), built information management systems and integrated new data to expand existing approaches to health and safety. Consolidating information from past incidents helps the industry to learn from past failures, and to design and implement measures that will help prevent the reoccurrence of tragedies such as the Grenfell Tower fire that killed 72 people in London in June 2017.

ABOVE *Construction, one of the world's most dangerous industries, was an early focus of Discovering Safety, a joint Foundation and HSE project to use data analysis to enhance safety.*

fStop Images GmbH/Alamy Stock Photo

ABOVE *Biases were present in the data that was used in vehicle design: crash test dummies were modelled on male bodies. Sharing data can help identify such biases and gaps that could have safety implications.*

Going further than ever before to uncover safety data, Discovering Safety is making a wealth of searchable documents available free of charge. In association with data governance specialists Ohalo, an auto-anonymisation tool has been developed that will allow data to be more widely shared by removing sensitive information. As part of the programme, HSE is collaborating with LR and other industry partners in the UK to develop the Severity Scanner. Combining artificial intelligence with machine learning, the Scanner will give safety professionals the ability to analyse unprecedented quantities of safety data on the causes of incidents and accidents. The outcome will be advice to industry on what to do to prevent the same things from happening again. Still in its preliminary stages, the Scanner is already being used to detect trends in occupational accidents using HSE's own database. It will give organisations the confidence to learn lessons from each other by anonymising shared accident reports. As a pilot project, it forms part of the LR SafetyScanner initiative, which fulfils the same purpose on a bigger scale.

Sharing collated, analysed and anonymised data has the potential to enhance safety in many areas if the users can have confidence in the way it is utilised. Engineering is one such area. To give users the required confidence, the UK's Open Data Institute (ODI) worked with other partners to draw up principles governing the sharing of engineering data for public benefit. The ODI manifesto, launched in 2019 and supported by the Foundation, also emphasised the importance of looking after data, fostering skills in its application and analysis, and ensuring it was used legally and ethically.

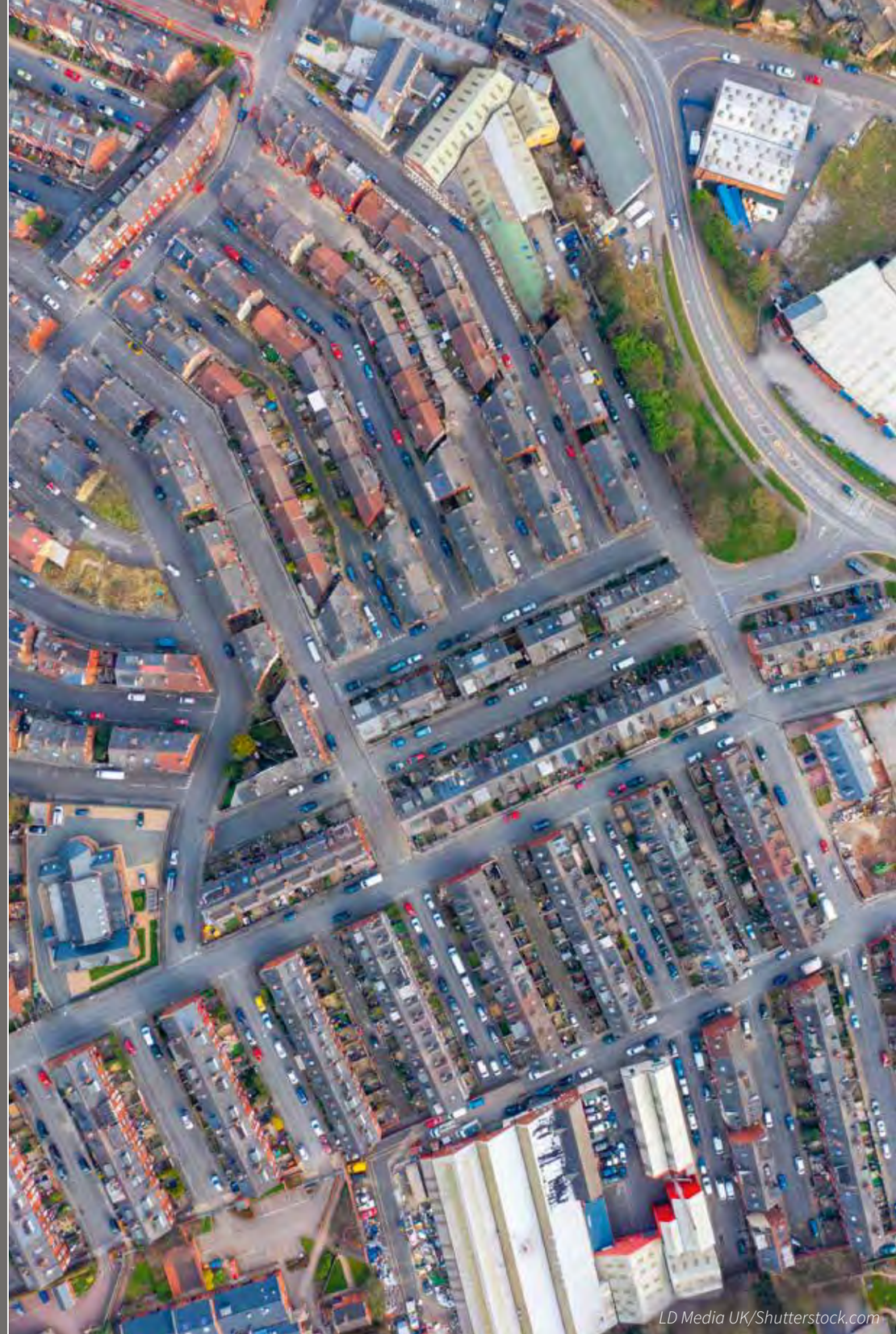
Professor Patrick Wolfe, then Professor of Statistics at University College, London, has observed how the Foundation understood 'the value of becoming an early investor in an area with huge potential to transform engineering and create benefits for mankind'. A series of UK projects followed, also backed by the Foundation, to promote greater access to engineering data.

Open data is being used to raise safety standards at sea and in the air. The University of Southampton is working with the UK's Maritime and Coastguard Agency to develop an open marine data pool to help report and respond to incidents at sea. The Data Science Campus of the UK's Office for National Statistics is collaborating with the Royal Air Force to analyse historical flight safety reports to enhance the safety of future flight planning.

A BREATHING CITY

Air pollution has become a major hazard in heavily populated communities worldwide. The WHO attributes 4.2 million deaths to outdoor air pollution every year. Many cities are declaring climate emergencies. One of the projects flowing from the ODI manifesto, illustrating the public benefit of sharing data, was designed to improve the air quality in the city of Leeds in the UK. This is one of five projects jointly funded by the Foundation and the ODI. In partnership with Leeds City Council, Slingshot Simulations are exploring the use of open data to help devise a digital twin simulating the city's air quality. The information will help inform the public and assist the city in moving towards its objective of becoming a 'Breathing City', successfully managing health risks from air pollution by understanding how pollutants are transported through urban environments.

OPPOSITE *Using open data to develop a digital twin of the air quality in Leeds, UK, will inform public understanding of health issues, finding ways of improving air quality to move towards a Breathing City.*



LD Media UK/Shutterstock.com

Safety at sea was the main objective of the HiLo Maritime Risk Management initiative established between the oil company Shell, shipping operator Maersk and LR's consulting business in 2016. The inspiration for the scheme came from former master mariner Manit Chander. During his time at sea, he had been concerned that proper risk assessments were hindered by a lack of data, which was impeding efforts to reduce the most frequent maritime accidents. He believed the answer lay in persuading shipping operators to share their data for analysis to identify common risks, which would lead operators to make better decisions and result in fewer accidents.

HiLo (short for 'High Impact, Low Frequency') spent three years developing an effective analytical, statistical model before asking companies to share data. Assuring the security of anonymised but commercially sensitive information was critical in winning the trust of operators in a conservative industry. Initially, companies restricted the information they shared, and it was only after some 12–18 months as their trust in HiLo grew that the flow of data increased. Trust, said Manit Chander, takes a long time to build through persistence and consistency.

After HiLo became an independent not-for-profit organisation, it built up the number of participating operators to more than 60, thanks in part to funding from the Foundation. Today HiLo brings together data from some 4,000 ships. There has been a dramatic reduction in accidents, including explosions, uncontrolled loads and fuel spills. At the Safety4Sea Conference in London in 2019, Chander told the audience that there had been a reduction of 72% in the risk of lifeboat accidents, 65% in the risk of engine room fires and 25% in the risk of bunker spills. Sharing data and learning from incidents recorded by other operators make it possible to predict the number of accidents for any one company. For example, when HiLo informed one company of an incident involving the failure of wires on a rescue boat, a check by the company revealed two boat wires were on the verge of snapping.

Petros Giannakouris/AP/Shutterstock

ABOVE *HiLo uses predictive risk modelling to identify potentially high-impact events and stop disasters in their tracks.*

RIGHT *'An accident that nearly ended my career inspired me to do everything possible to improve safety at sea', says Manit Chander, CEO, HiLo Maritime Risk Management.*

Sam Barker Photography/Lloyd's Register Foundation

In South Korea, the International Centre for Advanced Safety Studies (ICASS), which specialises in ocean safety, has placed its test data on an open digital platform for scientists and engineers worldwide. Its state-of-the-art, large-scale test facilities were built with government funding secured through an initial grant from the Foundation.

Open data programmes are being used by nation states as a way of increasing public involvement and sharing information more widely. The World Wide Web Foundation, for example, investigated the use of open data in a range of nations, from India to Brazil. In 2013, the Brazilian city of São Paulo launched an online tool called Cuidando do Meu Bairro ('Caring for My Neighbourhood'), which visualised the city's budget on an interactive map. In 2019, Code4Kenya, one of the Code4Africa pilot projects, developed applications and services relating to water, health and education data, with the aim of making such data more transparent, increasing public involvement and improving the delivery of services.

The main concerns around big data (see Chapter 5) are probably trust, transparency and security. While regulators struggle to implement effective

Cuidando do Meu Bairro (CMB)

rules for a phenomenon that transcends national boundaries, many organisations are turning to technology for help. Blockchain technology is proving to be one of the most successful ways of protecting data and ensuring its integrity. Blockchain makes it possible to share data across a network over multiple sites, organisations or countries, using cryptography, or secure communication techniques, to create a permanent, transparent, tamper-proof record of activities between parties sharing the network. Verification comes from a consensus of its users that any particular transaction is valid, these transactions are gathered into blocks, and chained together using cryptography, thus ensuring any attempt to alter any transaction will be visible.

Although in its infancy, the technology has already proven its worth. It has helped logistics technology company Marine Transport International verify the weight of packed shipping containers before they are loaded. In Denver, Colorado, USA, it is allowing patients and doctors to share sensitive medical information. Smart contracts specify the data which can be easily and securely transferred and even display details of personalised health plans for each patient. As consumers place a higher priority on the ethical sourcing of food, blockchain has been applied by Project Provenance to give them confidence in a product, its characteristics and ownership. For instance, Provenance can track tuna from where they are caught off Indonesia to their point of sale. The information it provides about supply chains can assist parties to counter the impact of modern slavery, although this is not without difficulty in terms of privacy, trust and veracity. Blockchain can also ensure the integrity of maintenance logs where assets such as aircraft are serviced in multiple locations.

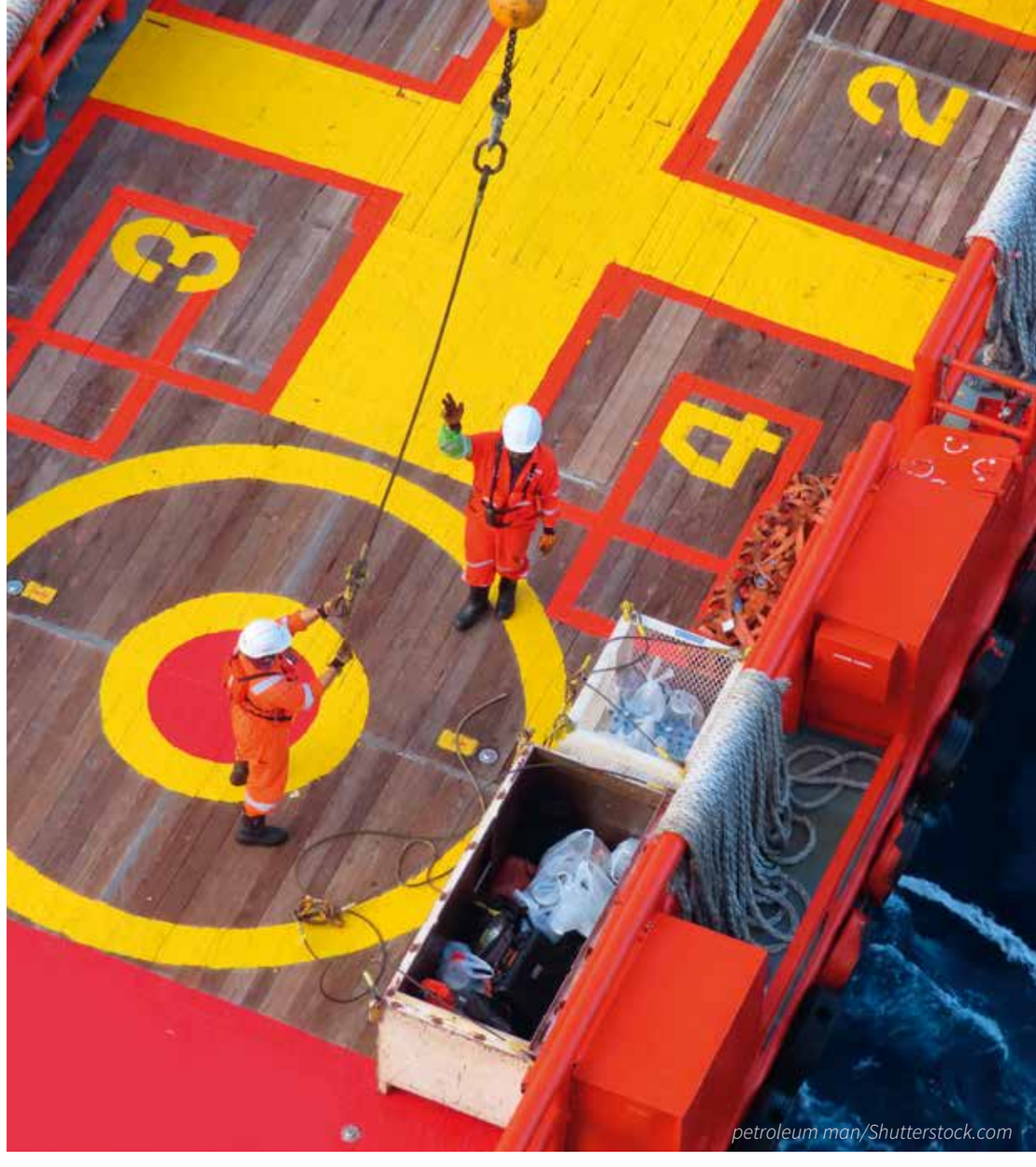
OPPOSITE *São Paulo's open data online tool enables people to find out about the city's budget and expenditure on an interactive map.*

OVERLEAF *Using blockchain, Provenance can track tuna along the supply chain to give consumers confidence in the product.*

Ariful Azmi Usman/Shutterstock

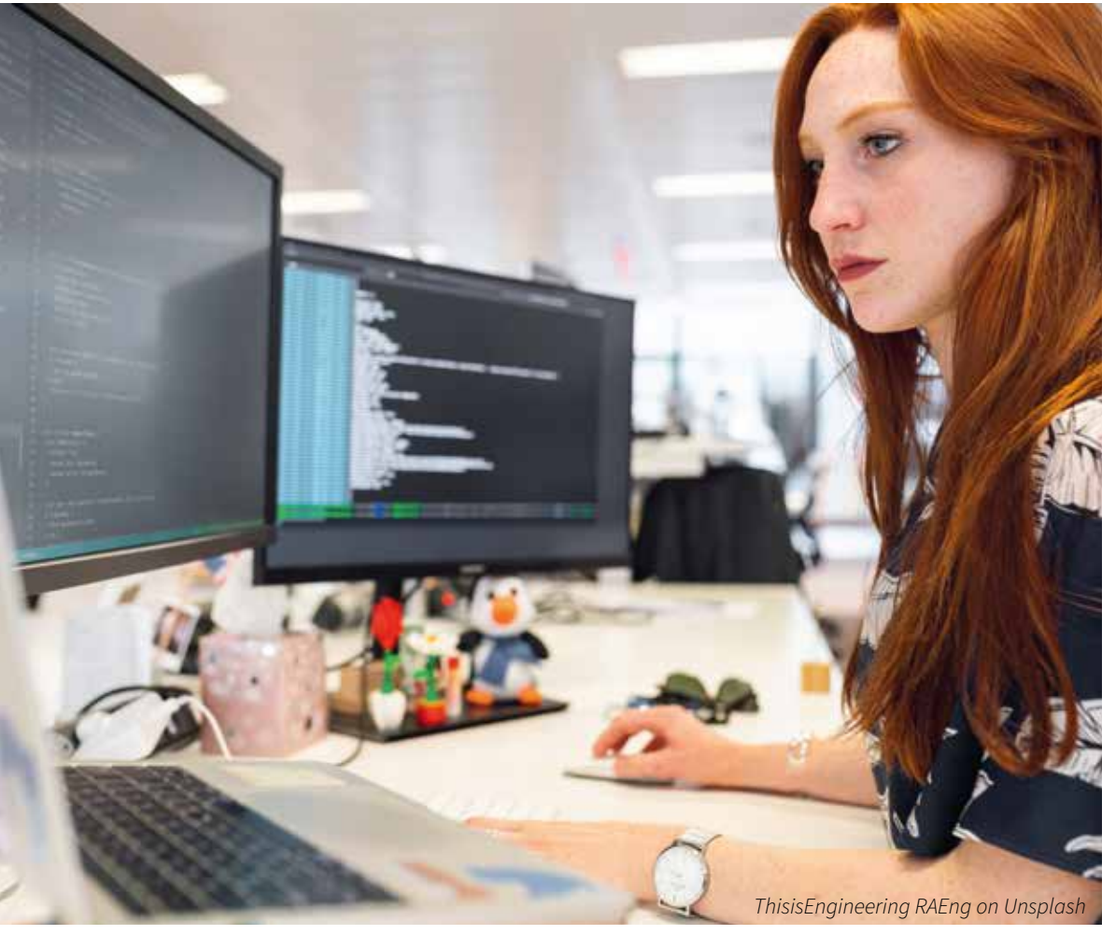
Blockchain is being used to assist shipping in becoming cleaner, greener and safer. Three pilots, supported by the Foundation, were launched by independent blockchain studio BLOC, as the Maritime Blockchain Labs project in 2020. One is helping the industry comply with the International Maritime Organization's rule for reducing the sulphur content in heavy fuel oil as a first step towards cleaner energy at sea. Blockchain has given vessel owners a secure and transparent platform for exchanging data on fuel quality, giving them confidence that they are complying with the rules. A second is using blockchain to set up a system to validate crew records, reducing the risk of operators recruiting seafarers without the appropriate qualifications. The third pilot tackles the longstanding problem of misdeclaration of hazardous goods, which is considered by many in shipping, including classification societies, to be the main cause of fires occurring at sea. For example, a fire stemming from this cause on board the *Maersk Honam* in 2018 killed five crew and injured many more. Creating a blockchain single ledger for immutably recording every transaction in the supply chain reduces the risk of misdeclaration.

The challenge will be to ensure that blockchain does not fall under the effective control of a handful of tech giants, which would defeat its purpose. Currently the technology also places too much emphasis on the creation of trust between servers rather than between human participants. Furthermore, blockchain has a heavy carbon footprint because of its intensive use of computing power. Although attempts are being made to reduce this, the example of Bitcoin mining illustrates the dangers of our thirst for data. As Bitcoin transactions multiply, the cryptocurrency demands ever more computing power to add them to its blockchain. The electricity used in creating Bitcoin to spend or trade was estimated in 2021 to be around 91 terawatt-hours every year, which is more than the annual consumption by Finland's 5.5 million people. All this is impeding the global campaign to combat climate change. In the USA, for example, obsolete power plants are being revived to provide the energy demanded by Bitcoin mining companies and thereby increasing the emissions destabilising the climate.



petroleum man/Shutterstock.com

ABOVE *A pilot project is using blockchain to set up a system to validate crew records, reducing the risk of operators recruiting seafarers without the appropriate qualifications.*



ThisisEngineering RAEng on Unsplash

ABOVE *Data-centric Engineering uses data-science to build data-driven models of complex engineering systems that can be used to tackle major global safety challenges.*

DATA-CENTRIC ENGINEERING

Big data has opened new avenues in engineering. One of the biggest advances is the emergence of Data-centric Engineering, with the capability of tackling major global safety challenges, including the reduction of greenhouse gas (GHG) emissions. While engineering has always made use of data, Data-centric Engineering has taken advantage of the technology, making it possible to gather data on a massive scale and analyse it with great precision. It is a new discipline for the modern era.

It owes its origins to Lloyd's Register Foundation. Its visionary review of big data, subtitled 'Towards Data-centric Engineering', was published in 2014. When Director of Research Dr Ruth Boumphrey searched for the term online, the nearest approximation she could find was a Texan plumbing business.

The Foundation's review coincided with the decision of the UK government to create a national data science institute to help the UK remain globally competitive. However, the newly founded Alan Turing Institute (ATI), named after the great British computer scientist, omitted engineering from its plans. The Foundation's Chief Executive, Richard Clegg, persuaded the government to rectify this omission, pledging the Foundation's commitment as a founding partner. Accordingly, the Foundation awarded ATI a £10 million grant in 2015 to fund a Data-centric Engineering programme. In 2017 Mark Girolami, then Professor of Statistics at Imperial College, London, was appointed as its head, noting:

> 'It was a completely new thing, it wasn't on the agenda of the ATI at all, you couldn't go to a university anywhere in the world and say I want to do a course in Data-centric Engineering, you wouldn't find any engineering company recruiting data-centric engineers.'

Mickey Lee Mediamixer.co.uk/ Lloyd's Register Foundation

LEFT *Professor Mark Girolami led The Alan Turing Institute-Lloyd's Register Foundation programme in Data-centric Engineering.*

OPPOSITE *Data-centric Engineering makes the world a safer place by improving the way engineered structures are designed, built and maintained.*

From the outset, Girolami could see the bigger picture.

> 'It was clear to me there was a much bigger ambition, that there was a whole new discipline that could be established, that would really transform the way that engineering could be conducted across all the engineering disciplines. There was the potential for an absolute transformation.'

The programme was intended to make data science and mathematical and statistical techniques an integral part of day-to-day engineering. The objective was to make the world a safer place by improving the way buildings, transport systems, energy networks and other engineered structures were designed, built and maintained.

Today Data-centric Engineering is taught at universities around the world. 'It's been a great partnership between the Foundation and ATI,' says Girolami, 'in establishing and launching a whole new discipline that not only academics have embraced but the various professions now see as absolutely critical to the businesses they support and to some of the crises that affect the globe.

Karl MPhotography from Pexels

We really have given birth to a whole new discipline, a whole new set of professions, and that's been really exciting.'

Girolami and his team were intent from the beginning on translating research into practical applications.

> 'Right at the very start, I said we were here to make a difference, we want to be playing a part in changing the world for the better, publishing papers is not what we're about, changing the world is what we're about. If we couldn't say this is the world's first, this is going to transform x or y, then we weren't going to do it. We ended up supporting the world's first 3D-printed bridge, the UK's first remotely monitored railway bridge, the first subterranean farm in disused underground railways, the first time that London was able to enhance or super-resolve the data we were gathering to improve air quality, and on it goes.'

ATI teamed up with the Cambridge Centre for Smart Infrastructure and Construction (CSIC), led by Professor Lord Robert Mair. The Centre was leading the way in using digital sensors to capture real-time data for monitoring major structures. In 2016 the Centre installed a monitoring system on the 150-year-old Marsh Lane viaduct in Leeds. The track operator, Network Rail, was concerned about its safety and believed it might have to be demolished and rebuilt at great expense with the lengthy disruption this would cause to traffic in the city centre. Data from the sensors was transmitted for analysis by the ATI and Imperial College, London. This concluded that the viaduct was structurally sound. The sensors remain in place, continuously monitoring the viaduct's condition. Doing away with physical inspections eliminates the need for disruptive road closures, while any deterioration in the structure is more quickly identified through the real-time transmission of data. ATI and CSIC have since carried out similar projects for Network Rail, including two new self-sensing railway bridges in Staffordshire, creating intelligent digital twins of the structures.

Zero Carbon Farms/Paul Marc Mitchell

Another pioneering project carried out by ATI and CSIC is an underground hydroponic farm hidden in the tunnels of a former Second World War air raid shelter beneath Clapham High Street in south London. Urban farms like this help shorten food supply chains, reduce GHG emissions, improve traceability, and increase the availability of fresh food for densely populated communities. Data-centric Engineering allowed the operators to maximise the farm's efficiency. Sensors transmit data to a distant digital twin, which creates a visual representation of the farm. Growing conditions, including the use of heat, light, water and nutrients, can be altered according to the data, improving sustainability and maximising crop yields. According to Melanie Jans-Singh, one of the research team, 'What the digital twin shows is better than being in

ABOVE *A pioneering Data-centric Engineering project involves an underground hydroponic farm hidden in a former air raid shelter in south London.*

Sunshine Seeds/Shutterstock

the tunnel in person – it can monitor, learn, feedback and forecast information that will make the real-life twin work better.'

When ATI formed a partnership with leading UK engineering business Rolls-Royce, applying Data-centric Engineering to create a more efficient jet engine design, the results were made available to the wider engineering profession on an open data platform. ATI's work contributed towards the 2019 Lloyd's Register Foundation report promoting the advantages of sharing engineering data for the public good.

In London, in partnership with the Greater London Authority and Transport for London, ATI investigated how the collection of data from mobile networks and traffic cameras could be used to map the levels of air pollution in the city. When the pandemic hit the city, the team adapted their approach to capture data from cameras and sensors in every borough to help the health and transport authorities understand how human behaviour was changing in response to government policy. A 30-strong team produced daily reports from traffic feeds. This allowed the authorities to make the changes needed to keep people safe at the peak of the pandemic, such as moving bus stops and opening cycle lanes.

The ATI team also took part in the construction of the world's first 3D-printed bridge in Amsterdam (see pages 204–209). As Gijs van der Velden from the bridge's developers, MX3D, explained, it was 'a very symbolic project'. Siting it in the middle of the city spanning the Oudezijds Achterburgwal canal was a way of showing people that the technology of 3D printing was approved, safe and could be applied to larger structures.

OPPOSITE *ATI and Rolls-Royce applied Data-centric Engineering to create a more efficient jet engine design and made the results available to the wider engineering profession on an open data platform.*

NANOTECHNOLOGY

Working on the nanometre scale – a nanometre is the equivalent of one billionth of a metre – is not without its challenges but the *Foresight Review of Nanotechnology* published by the Foundation in 2014 highlighted the remarkable advances made by the science in recent years. As the review observed:

> 'Imagine a material orders of magnitude stronger than steel yet a fraction of the weight; materials that can heal themselves and self-repair when damaged; structures made from materials that can "feel" the forces acting on them and communicate; liquids that can transform into solids and back again at will thus able to absorb shocks; wires and electronics as tiny as molecules; ultra-high density energy storage batteries and capacitors; artificial intelligence; DNA-based computing; nanoelectromechanical actuators and nanorobots. All of these are already existing or foreseeable applications of nanotechnology. … Its applications will impact almost every industry including energy, transportation, manufacturing, medical, computing and telecommunications.'

Nanoscience Centre, University of Cambridge

LEFT *Nano flower bouquet, a three-dimensional nanostructure grown by controlled nucleation of silicon carbide nanowires.*

Jakub Kostal/Thinkstock

ABOVE *Engineering at the nanometre scale, with respect to 1m length, is like being able to position a single eye of a common housefly to an accuracy of less than one-tenth of its diameter in the distance between Paris and Rome.*

Luca Zennaro/EPA-EFE/Shutterstock

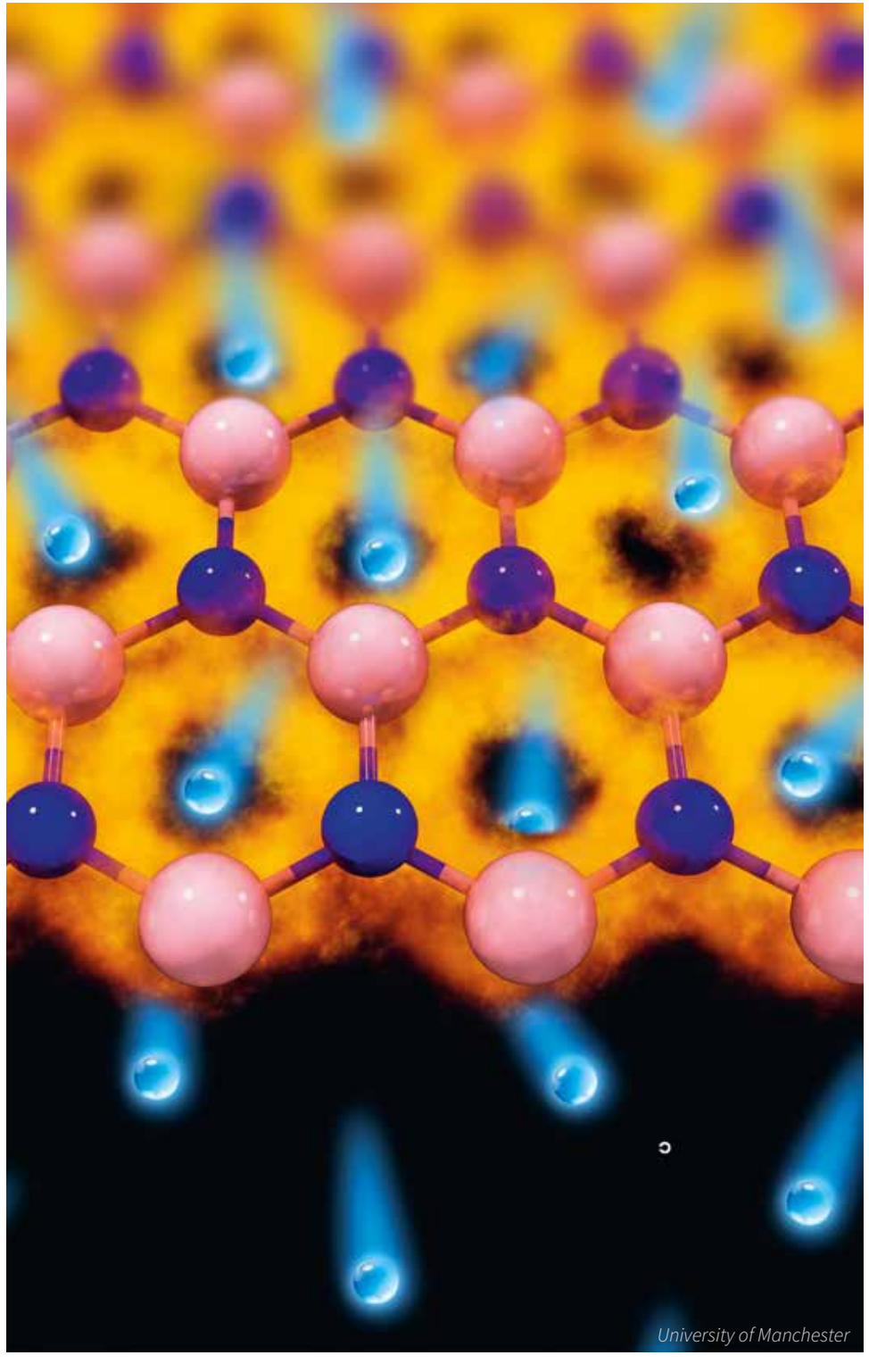
Linking advances in nanotechnology with advances in data collection and analysis was the key to unlocking many of the benefits of big data. The volume of data relayed in real time through continuous monitoring by tiny digital sensors has improved the safety of buildings, bridges and other structures. Research is underway to apply nanosensors for use in medicine. Implanted within a patient, they would notify clinicians when treatment is needed much earlier than conventional methods. Nanotechnology is another weapon in the armoury for tackling climate change. Nanomaterials used for insulation can reduce the energy required for heating buildings and other structures. Wind-turbine blades using lighter, stronger nanomaterials are more energy efficient. So too are solar panels coated with nanofilters. Nanomaterials even create the possibility of structures that could heal themselves when worn or damaged, preventing small fractures from becoming larger. Nanotechnology is already evident in smaller, more energy-dense phone batteries, compact fuel cells, photovoltaic cells and super-capacitors for storing electrical energy.

Arising out of the Foundation's *Foresight Review*, three major international projects in nanotechnology were initiated. As Dr Boumphrey puts it, 'We are here to enable clever people to be clever and put their cleverness into action to change the world for the better.'

OPPOSITE *The San Giorgio Bridge was completed in 2020, two years after the shocking collapse of the Morandi Bridge in Genoa, Italy. Its innovative technology includes sensors placed along the 1,607m bridge to measure movement, such as joint expansion. High-resolution cameras and sensors on two robotic arms also transmit data to engineers, forming a futuristic central nervous system.*

One project involved a team headed by Nobel laureate Professor Sir Andre Geim at the University of Manchester in partnership with several overseas institutions. This studied the application of one-atom-thick materials (nanomaterials), including graphene, for safety purposes, such as desalination, an important step forward in a world where water resources are under pressure. At the University of Cambridge, Professor Sir Mark Welland and his team headed a similar international consortium exploring the use of nanotechnology for improving the subsea transmission of power.

The third major project aimed to promote knowledge and research in nanotechnology worldwide. With shared knowledge the key to maximising the technology's worldwide potential, Professor Themis Prodromakis and his team at the University of Southampton embarked on the creation of the first international nanotechnology research network, the International Consortium of Nanotechnologies (ICoN). The Consortium aims to apply nanotechnology to risk assessment and devise practical ways of enhancing safety. 'The investment from the Foundation,' said Prodromakis, 'really helped us to focus nanotechnology on making the world a safer place.'



University of Manchester

OPPOSITE *Artist's impression of protons permeating through a two-dimensional crystal. University of Manchester research has revealed a new generation of proton-conducting membranes that can revolutionise hydrogen technologies, fuel cells and energy storage.*

Links were made with universities around the world, from Stanford and the Massachusetts Institute of Technology in the USA, to Sydney and Perth in Australia. As with many projects supported by the Foundation, ICoN has collaboration at its heart as a way of fostering global connections to overcome geographical boundaries and encourage researchers from different disciplines to work together. 'What we were proposing,' recalled Prodromakis, 'was going beyond disciplinary boundaries, so we had to develop a common language for people when we were coming together.' The doctoral research projects part-funded by ICoN, with minimum match-funding from the recipients, effectively established an international cohort of nanotechnologists, some 200-strong, covering 16 countries. While 95% of them have established careers outside academia, many have also formed their own research groups, forging their own networks to carry on where ICoN leaves off. ICoN's strength lies in the diversity of its people, as Prodromakis noted:

'There were different cultures, different languages, different access to facilities, different levels of support, and although that was a challenge, it ended up being one of our strengths. Every single person, every development, everyone's story is unique. We wanted to embrace diversity and help everyone identify their personal strengths as well as the strengths of their research and help them to move forward.'

LEFT *As with many projects supported by the Foundation, ICoN has collaboration at its heart as a way of fostering global connections and encouraging researchers from different disciplines to work together. Currently it has linked together 51 projects around the world.*

ICoN shows the value of collaboration, sharing ideas, motivating and inspiring people to achieve practical solutions. 'For the first time,' said researcher Dr Rebecca Boston, 'scientists like me can build our research groups and collaborate across continents and institutions to ensure that humanity gains the maximum benefit from these incredible technologies.' The ICoN model helped pave the way for similar international collaborative projects with which the Foundation is involved, such as the Engineering X programme (see page 155). Researchers were encouraged to explain their work in terms anyone could understand. A novel way of embracing this objective was creating a pack of playing cards, each card succinctly summarising an individual project with a mix of images and a few words, ranging from sustainable high-performance batteries for safe and efficient energy storage to safety profiling for better understanding of nanomaterials in the environment.

The Amsterdam 3D-printed bridge mentioned earlier was intended as a tangible example of how nanotechnology, through 3D printing, could be applied safely to larger structures. It demonstrated how emerging technologies, in this case nanotechnology, Data-centric Engineering and big data, can overlap. MX3D, the Dutch company who first proposed the project in 2015, and Autodesk, the US software engineers, applied sensors to the bridge to build a digital twin to relay information in real time on the performance of this pioneering structure. Support from Lloyd's Register Foundation allowed MX3D to tap into the Foundation's research network, bringing onboard partners such as ATI, The Welding Institute (TWI) and Imperial College, London. ATI carried out the data analysis to create the twin; Imperial undertook testing and helped design the network of sensors; and TWI was involved in devising guidelines for the production process. In addition, LR's quality assurance business assessed the system.

The team were confident in the technology. A lot of research was carried out into materials and the engineering: understanding the behaviour of the materials helped to improve the design. And as a unique project, it was important to incorporate as much safety as possible, ensuring that if something went wrong, there were multiple backups available.


Sam Barker Photography/Lloyd's Register Foundation

LEFT *Dr Rebecca Boston, a Lloyd's Register Foundation and Royal Academy of Engineering Research Fellow at the University of Sheffield, has benefited from the ability to collaborate through the ICoN network.*


Thea van den Heuvel/MX3D

ABOVE *The MX3D 3D-printed bridge in Amsterdam is a tangible example of how nanotechnology, through 3D printing, can be applied safely to larger structures.*

Professor Mark Girolami from ATI recalls that, as the bridge was being printed, a process that took six months, someone asked what the structural properties of 3D-printed stainless steel were, and nobody knew. The next question was 'Is it going to be safe?' and again nobody knew. 'I pulled together a team of structural engineers, material scientists, statisticians, applied mathematicians, mathematicians of a very exotic variety called stochastic geometers, who were amazed that anybody wanted to talk to them outside of their discipline, computer scientists and physicists, because we needed to understand what the material properties were, what the structural properties were and will this bridge actually stand up. None of them would have spoken together before. I remember the first meeting of the structural engineers and the statisticians, and I was like a Babel fish acting between them. And yet we delivered, satisfied the regulators that yes, this is safe, we got insights into the material properties and how they were impacted by the way the material was additively put together and the control of that.'

All the printed elements were held together by a steel plate forming the top layer of the bridge, the only non-printed component, which provided additional confidence that the bridge would not fail. After it was completed, it was tested with a 20-tonne load, again to give confidence in its integrity. Many in the professional world were initially sceptical about a printed bridge – was it useful, was it necessary, was it safe? – but safety concerns disappeared. The structural engineers involved went on to work on the international design standards that apply to this type of material and structure.

While the bridge's design has divided opinion, most people appreciate the technical achievement. 'Everybody likes that part, it still has something magical, that you can print any kind of shape,' said Gijs Van der Velden of MX3D.

'That element of 3D printing is something people never get bored of, and on that scale it makes an impact, and plays with the imagination. For us, it's a playful project, we didn't want to make the most efficient 3D bridge or anything, we just wanted to amaze and show people what is possible, and that is something people don't do very often. Most people just enjoy the playfulness of it.'

BELOW *'We're building a bridge to a new way of thinking about critical infrastructure,' said Gijs van der Velden, MX3D.*

Sam Barker Photography/Lloyd's Register Foundation

Olivier de Gruijter/MX3D

LEFT *The metal-printing process used by MX3D is radically faster than any previous 3D-printing technology, but it cannot yet compete commercially with standard materials of construction. The bridge demonstrates that traditional elements can be combined with 3D-printed parts for bigger developments.*

The bridge finally opened in July 2021. For Dr Jan Przydatek of Lloyd's Register Foundation, 'It was a moon shot, an amazing moon shot, which has inspired people across the globe about what is possible'.

While the metal-printing process used is radically faster than any previous 3D-printing technology, it cannot yet compete commercially with standard materials of construction. But the bridge has demonstrated that there are possibilities for components and exceptional structures. Traditional elements can be combined with 3D-printed parts for bigger developments. The project has shown that there is an effective process which achieves reliability and quality in printing 3D structures. And the data-centric approach has created a full digital design-and-build system, which can provide data for building safer and more reliable structures in the future: smart buildings consume less material and less energy and have a lower carbon footprint.

ROBOTICS AND AUTONOMOUS SYSTEMS

Robots have captured the human imagination for decades. The popular conception of the quasi-human machine only recently seemed a distant dream. But advances in artificial intelligence (AI) and software engineering are creating robots with intellectual and mechanical capabilities once seen only in science fiction. Today robots tend to fall into three main categories – industrial robots, robots for professional use, from medicine to construction, and autonomous vehicles. A *Foresight Review* by the Foundation in 2016 summed up their impact.

> 'There is a revolution happening around us and all over the world. Smart, connected machines, or robotics and autonomous systems (RAS), are acting as tools to support us, working alongside us or alone, making independent decisions and even learning. They act and sense in the real world, connected and collaborating in the Internet of Things, generating and enabled by large quantities of data, using artificial intelligence to reason, classify, control and interact. They have emerged from research prototypes into practical applications.'

Significant growth in the use of robotics is forecast, driven partly by consumer demand, partly by an ageing population, and partly by the rise in mundane but dangerous tasks such as recycling. Robots capable of autonomous learning are already possible, thanks to powerful, if energy-intensive, computing able to analyse massive volumes of data. More broadly, autonomous systems, which can tailor their behaviour and operation according to circumstances, are also developing rapidly. The most widely known examples are autonomous vehicles, which now encompass driverless ships, trains and automobiles.

James Wakibia/SOPA Images/Shutterstock

Robots can reduce human risk and improve safety in many fields. They can be used to distance people from potential harm, for example, for the remote inspection of offshore installations. By taking over more repetitive jobs in industrial situations, and enabling workers to concentrate on more engaging tasks, they remove the tedium and complacency which are major contributors to industrial accidents.

ABOVE *A worker loads plastic bags on a conveyor at a recycling plant in Kenya. Mundane but dangerous tasks such as recycling will be a growth area for robotics.*

OVERLEAF *Robotic-assisted surgery is less invasive than open surgery, giving a surgeon enhanced vision, precision, dexterity and control.*

BSIP SA/Alamy Stock Photo

THE FIRST CYBER AL-SAFE SHIPS

The world's first ships to be awarded the LR notation Cyber AL-SAFE (autonomy level safe) were delivered to Global United Shipping in South Korea in 2017. According to LR, which certified the safety of the onboard autonomous systems, they were the first true examples to represent the digital transformation currently taking place in shipping. With the rapid pace of technological change, it is no longer safe to rely on existing systems. A safety assessment requires what is described as a total systems approach, essentially assessing each case on its merits.

For Global United, it was in their commercial interest to adopt autonomous technology. It helped make their operations more efficient, partly because it reduced the risk of human error, the principal factor in accidents at sea.

Peter Faas

ABOVE *The LPG tanker* Trammo Dietlin *operates in an autonomous mode for selected functions using cutting edge digital technology. The cyber-enabled features allow the crew to operate the ship more efficiently. This is also the first example of a ship certified to stream data into a big-data platform.*

Many experts believe that machines more intelligent than humans will be developed by the end of the 21st century. The accelerating rate of change challenges the resilience of robotics and autonomous systems, and poses significant safety risks, from their vulnerability to cyber-attacks to the ability of human operators to respond to their failure. As the Foundation review put it, assuring the safety of robotics and autonomous systems is imperative in realising their potential as 'assistants in the service of a safer world'.

In recognition of this fact, the UK government funded several robotics centres focused on specific industries. In 2017, for instance, the Offshore Robotics for the Certification of Assets (ORCA) hub was set up alongside the Oil and Gas Technology Centre (since renamed Net Zero Technology Centre) in Aberdeen. The partners included LR (providing support and technical expertise) and several UK universities (such as Heriot-Watt, which hosts the ORCA hub), as well as offshore energy companies interested in raising safety standards through robotics.

The way humans and intelligent machines connect is the focus of the Assuring Autonomy International Programme (AAIP) led by the University of York. Supported by the Foundation, AAIP's purpose is ensuring the safety of autonomous technologies for public benefit. The programme, which began in 2018, is led by Professor John McDermid and his team in York. 'Our focus has always really been on safety,' he said, 'and how you assess how safe systems are, what works well, what can go wrong, and if things do go wrong, how you control that to keep people safe.'

As autonomous systems have become more complex, with increasing authority to act without human intervention, ethical considerations have become important, and several members of the AAIP team have a background in philosophy. The challenge in transferring decision-making to computers is understanding the limits of AI and machine learning. Intuitive thinking is thus far beyond machines, and the technology must take this into account to minimise the risk of failure and keep people safe.

Research projects into autonomous systems have been established in Europe, North America, Australia and Japan, and course materials made available for universities elsewhere, including Vietnam. Among current demonstrator projects, four research partners in Stockholm are studying

ABOVE *Assuring the safety of robotics and autonomous systems is imperative in realising their potential as assistants in the service of a safer world.*

ABOVE *Gathering sensor data from an autonomous vehicle as part of the Sense-Assess-Explain project funded by the AAIP.*

how autonomous ships can operate as safely at sea as crewed vessels. Since moving the captain onshore to monitor a single vessel is not cost-effective, one individual will be expected to monitor multiple vessels, and the project is investigating the safety implications. In London, a team from Imperial College, which has devised the AI Clinician algorithm for providing suggested doses of medication in cases of sepsis, are using collated clinical knowledge to assure the system is safe. In Bristol, researchers are assessing how robots and AI can be used safely to maintain the independence of the elderly and infirm. This is critical if such systems are to win the trust of patients, clinicians and healthcare workers.

The AAIP is translating its research into advice for developers, regulators and others through online resources and freely available publications. The online resources, under the title Body of Knowledge, are continuously updated, providing practical guidance on assurance and regulation. At the core of the programme is the belief that its work can help ensure safe and trusted systems benefit society. 'This is the underlying driving force of what we do,' said McDermid. 'I am positive that we are making a difference.'

At the core of the Assuring Autonomy International Programme is the belief that its work can help ensure safe and trusted systems benefit society.

PROTECTING BIODIVERSITY THROUGH AI

At the end of 2021, Wildlabs.net, the conservation technology network, published a pioneering global report on the contribution technology was making towards biodiversity conservation. *The State of Conservation Technology 2021* reported that artificial intelligence was one of the top three technologies most useful in wildlife conservation. The report highlighted AI's capacity in combination with machine learning to accelerate the collection of vital conservation data. From camera traps and satellite images to audio recordings, AI is helping to protect species such as humpback whales, koalas and snow leopards. In Zambia's Kafue National Park, an 11-mile (19-km) virtual fence across Lake Itezhi Tezhi, operated by thermal cameras, records every crossing to help deter poachers. In Brazil, AI was used by researchers on the MapBiomas water project to establish how much surface water the country had lost over the last 30 years through the analysis of more than 150,000 satellite images. The data provides the evidence for future action to tackle the impact this loss has on the country's biodiversity. In Australia, AI is helping to conserve the declining koala population by identifying their location through the rapid analysis of video footage.

BELOW *The Juruá is one of the longest tributaries of the Amazon River, flowing slowly through the half-flooded forest it traverses in the Amazon basin. Given its size, remote sensing is the best way to study the Amazon basin on a large scale.*

Alexander Gerst (CC BY-SA 2.0) via Flickr

INTERNET OF THINGS

Many technologies overlap and form part of the smart systems generalised as the 'Internet of Things' (IoT). In 2017, IoT's annual economic impact was estimated to reach between US$3.9 trillion and US$11.1 trillion by 2025. As discussed in the Foundation's *Foresight Review of Cyber Security for the Industrial IoT*, smart systems can enhance safety and efficiency. Smart ports can utilise data to keep ships safer and enable autonomous ships, cranes and lorries to load and unload containers. Smart energy grids can better balance energy loads, maintain a continuous supply, and integrate production by renewable sources linked to weather conditions. Data collected by sensors in the built environment can flag the need for maintenance, identify safety hazards, and manage ventilation and heating. Factories can benefit from improved stock management, order processing and production planning.

As with other emerging technologies, the challenge is making sure that these systems operate safely and securely. IoT users surveyed by McKinsey in 2015 gave security as their primary concern. This has been borne out by the frequent attempts of hackers to shut down critical systems worldwide. In 2016, for example, the Mirai cyber-attack used IoT devices to bring down systems across Europe and North America, resulting in an estimated economic loss of around US$100 million.

Anucha Sirivisansuwan/Moment via Getty Images

OPPOSITE *Smart ports use automation and innovative technologies to improve performance and safety.*

The Foundation's review found this frailty is compounded by widening gaps in skills and awareness, inadequate cyber protection and the difficulty of devising adequate manual recovery plans as smart systems become more sophisticated. For instance, a failure of understanding led the managers of one road tunnel to disconnect its smart systems, affecting performance, safety and costs. A cyber-secure ship had its Ethernet cables stripped for sale and replaced by copper wires by its crew, oblivious of the dangers this created for ship, crew and passengers.

As a result, a wide range of smart measures to keep IoT systems safe are continuously updated to keep pace with changing external and internal threats. IoT developers are encouraged to consider safety and security not only during the design phase of any system but also during its operating life. When systems are running, continuous training for cyber-security teams is essential. Better information promoted more vigorously can help consumers understand cyber risks and take steps to ensure the safety and security of their own systems. This is vital as our daily lives become dominated by IoT devices and systems, from mobile phones, banking systems and cars to security cameras, televisions and refrigerators.

Burak K from Pexels

RIGHT *Drones can quickly reach a vantage point that humans cannot easily access.*

OVERLEAF *Firefighter drones help first responders in their rescue efforts.*

John Bazemore/AP/Shutterstock

REMOTE MONITORING

Robotics play their part in the trend towards remote monitoring and inspection, which enhance safety by eliminating the dangers often encountered in physical inspections. Investment in remote monitoring and assessment multiplied during the pandemic when worldwide lockdowns limited human interaction.

Drones, remote-controlled and autonomous, are employed to conduct inspections in difficult or otherwise inaccessible environments, such as offshore windfarms. They have the potential to operate in other areas. For example, an AAIP demonstrator project is investigating the use of drones to carry out more effective pre-flight external aircraft checks for pilots.

More recently, following the deaths of four rail workers over two years while inspecting track, Network Rail in the UK has begun adopting remote track inspection systems. As well as improving safety, digital remote inspection systems will replace the currently fallible manual methods of inspecting 1.2 million miles (1.9 million km) of track and 30,000 bridges using torches or binoculars. A pilot project began in 2021.

OPPOSITE *Managers of infrastructure with smart systems, such as road tunnels, need to have skills and awareness of how the system works.*

Nicolas Economou/NurPhoto/Shutterstock

LR initiated remote marine surveys in 2017. At the time, however, these were not seen as urgent within the shipping industry. As a conservative industry, shipping is rarely an early adopter and began introducing smart technology only when its benefits – such as improved fuel economy, more efficient monitoring and enhanced safety – became obvious. The restrictions imposed on human activity by the pandemic increased acceptance of the technology. Clients also discovered remote surveys were more cost-efficient, saved time and minimised operational disruption. As a result, they contribute to the well-being of crew by eliminating the pressure of the traditional maintenance cycle. LR helps to link ships with a global network of remotely located surveyors who guide crew through the process, involving technologies such as live streaming, drone imagery and static exchanges of images, transmitting data through the LR Remote app. During 2020 LR carried out one in three of its annual 30,000-plus surveys remotely.

BELOW *LR initiated remote marine surveys in 2017 and the Covid-19 pandemic accelerated the acceptance of this service. It uses technologies such as live streaming, drone imagery and static exchanges of images.*

Lloyd's Register Group

SAFETY ACCELERATOR

Robotics, nanotechnology and Data-centric Engineering are examples of technologies that can enhance safety. Specifically applying digital technology for the benefit of safety was the objective of one of the first major collaborations between LR and Lloyd's Register Foundation.

The Safety Accelerator programme, launched in 2018, matched the safety challenges of LR's clients with solutions devised by start-up tech companies. LR partnered with the Silicon Valley global innovation venture capital fund, Plug and Play Tech Center, to identify suitable start-up businesses able to work alongside LR's clients.

The programme brought benefits to both parties. It gave industry the chance to become an early adopter of innovation without the financial risk, and provide tech start-ups with funding and a route to market. 'The magic of it,' said the Foundation's Dr Jan Przydatek, 'is that these start-ups have already created technology for other purposes, such as financial (fintech) or medical (medtech) applications, and what we have done is help them move in the relatively new space of safety.'

The first programme featured 26 clients with safety-related projects, attracting interest from more than 600 start-ups worldwide. Early ideas for applying technology included tracing food allergens, improving fire detection systems on board car carriers and devising early warning systems for leaks on vessels carrying liquid natural gas.

Monkey Business Images/Shutterstock.com

ABOVE *Applying digital technology to improve safety was the aim of the Safety Accelerator. Early pilots for applying technology included tracing food allergens to make school mealtimes safer.*

One of the first pilots was with an international shipping company on the early detection of methane gas leaks on board gas-carrying ships. Methane is an invisible and highly flammable gas, with a huge global warming effect. The ability to detect leaks is crucial, given the impact of hydrocarbons on the environment, and the risks of explosion and asphyxiation. The initiative developed ways of using existing sensor technology for an alien application in a way that was safe on ship, given the dangers of using electronic devices on a gas carrier. Dynamic teams on both sides, LR's and the client's, came together to find a safe and appropriate way of applying the technology. The Foundation-supported Discovering Safety project (see page 174), an industrial partner of the Safety Accelerator, set the challenge of anonymising data in safety reports, thereby allowing them to be widely shared: a tech start-up which was already using AI to anonymise data teamed up with the UK's HSE.

Building on the early success of the programme, including a Lloyd's List Innovation Award in 2019, and to give the programme commercial stimulus, an independent not-for-profit company, Safetytech Accelerator, was set up by the Foundation and LR in 2021. Maurizio Pilu, who had transformed LR's approach to digital innovation, became Managing Director. Research commissioned by the Foundation estimated that a potential global safety tech market would be worth nearly US$900 billion by 2023. A future challenge for the Foundation is helping to unlock this potential to further enhance safety.

Ameya Mathkar/Lloyd's Register Group

OPPOSITE *A pilot exploring robotics to remove the need for humans to conduct inspections in confined spaces is one of the Safetytech Accelerator projects.*

Thomas Mukoya/Reuters/Alamy Stock Photo

CHAPTER 5:
FAKE NEWS AND PUBLIC TRUST

The term ‘fake news’ was first widely used in the late 19th century by newspapers seeking to disparage the journalistic integrity of their rivals.

LEFT *People queue to cast their vote outside a polling station in Nairobi, Kenya, 8 August 2017. Misinformation and propaganda around elections are not new in Kenya. In 2017, while social media fostered access to important information, it was also used to spread fake news, some disparaging the independent institutions managing the elections.*

The capacity of the influential in spreading disinformation has been known for centuries. It is the modern phenomenon of the internet and, in particular, social media platforms, which has made 'fake news' more pervasive and dangerous. One result is a failure or crisis of public trust in sources of truth about matters of fact which can be damaging to society.

One of Lloyd's Register Foundation's most important projects, the World Risk Poll, is tackling this issue by collecting evidence and insight for the first time on the differences between people's experience and perception of risk. The results are available for use by governments, regulators, industry and other organisations to help them develop effective policies to assist people to take action, thus giving them greater assurance over their safety and saving lives. The Foundation is also helping to finance the innovative Institute for the Public Understanding of Risk in Singapore (IPUR), founded in 2017, whose work covers many of the global safety challenges identified by the Foundation. The Foundation's own commitment to research based on robust evidence was furthered through the creation of its Evidence and Insight Centre in 2019.

THE IMPACT OF DISINFORMATION

The pandemic has underscored the dangers of fake news. South America is the most vaccinated region in the world, yet in early 2022 half the population of Bolivia had still to receive a single dose despite ample availability. One of the reasons is the misinformation peddled to a poorly educated rural population eager for knowledge. Much of this is circulating on Facebook and WhatsApp, the platforms used by most Bolivians, and spreads to traditional media, with television shows touting miracle cures.

The Center for Countering Digital Hate, founded in 2018, is an independent non-profit, non-governmental organisation, based in London and Washington, formed, as its title suggests, in response to the proliferation of digital disinformation. In a recent report, the Center found that just 12 people were responsible for most anti-vaccine misinformation and conspiracy theories, yet they had a combined following of 59 million people. Moreover,

James Brunker News/Alamy Stock Photo

ABOVE *Street art on a wall in La Paz, Bolivia, refers to Covid-19. The bottle of hand sanitiser represents fear, panic and disinformation, referring to the number of sensational articles about the virus in the news and on social media.*

only 5% of misinformation about Covid-19 was taken down by social media platforms. Another report published in the same year by researchers from the Massachusetts Institute of Technology (MIT) discovered that fake news travelled faster on social media than news from trusted sources.

While the MIT report found that humans are principally responsible for this trend, technology also plays its part. As Professor Stuart Russell, of the Center for Human-Compatible Artificial Intelligence at the University of California, pointed out in an interview for the World Economic Forum in 2022, social media algorithms already exert considerable control over what people choose to read and watch.

> 'A massive, human-driven industry has sprung up to feed this whole process: the click-bait industry, the disinformation industry. People have hijacked the ability of the algorithms to change people's minds very rapidly. Hundreds of interactions a day mean that everyone receives a little nudge. But if you nudge somebody hundreds of times a day for days on end, you can move them a long way in terms of their beliefs, their preferences, their opinions.'

Social media has also been exposed for the extent of its contribution to climate disinformation. In 2021 researchers discovered that 45,000 posts on Facebook minimising or denying the climate crisis had received as many as 1.36 million views. Stop Funding Heat, an environmental non-profit organisation, notes that the spread of such misinformation has seriously threatened the campaign to tackle climate change. In the US, oil executives have appeared before Congress to explain the industry's role in spreading misinformation about their plans to achieve net-zero carbon emissions.

Such trends can seriously undermine public trust and confidence in democratic and other institutions and polarise opinions based on information drawn from limited and dubious sources. The Dutch microbiologist Elisabeth Bik recently pointed out how flawed research papers can be championed on social media by propagators of disinformation and, as she put it, 'celebrated as the new truth'.

Penelope Barritt/Alamy Stock Photo

ABOVE *London, UK, 16 October 2019: people protest about Google making donations to organisations which have campaigned against environmental legislation and questioned the science behind the climate crisis.*

dpa picture alliance/Alamy Stock Photo

LEFT *In 2020, the Peruvian health system came under strain when many people, reading misleading online reports, demanded a livestock drug, Ivermectin, to counter the Covid-19 virus.*

Moreover, such propagators are becoming more sophisticated in their manipulation of digital media, as a report to the European Parliament observed in 2021. It emphasised that while disinformation has an adverse impact on human rights and democracy worldwide, endangers economic, social and cultural rights and fosters digital hate, countermeasures taken by some authorities can often have a similar impact by shutting down freedom of expression and taking away democratic rights.

Misinformation, as well as disinformation, without political agenda can spread just as rapidly. In 2014, a solitary text from a student in Nigeria advocating drinking salt water to avoid catching Ebola saw hundreds of tweets repeating the rumour. Before it was quashed by the authorities, however, the rumour had caused two deaths and led to many hospital admissions of people who had ingested too much salt. More recently, in 2020, as the Peruvian health system came under strain during the Covid-19 pandemic, misleading information advocating the use of a livestock drug, Ivermectin, to counter the virus reached many Peruvians online. This was taken up by a variety of different groups, from evangelical churches to local politicians, across a range of media platforms. Despite no information on the drug's efficacy for humans, many Peruvians self-administered Ivermectin, which was often prescribed by under-pressure doctors.

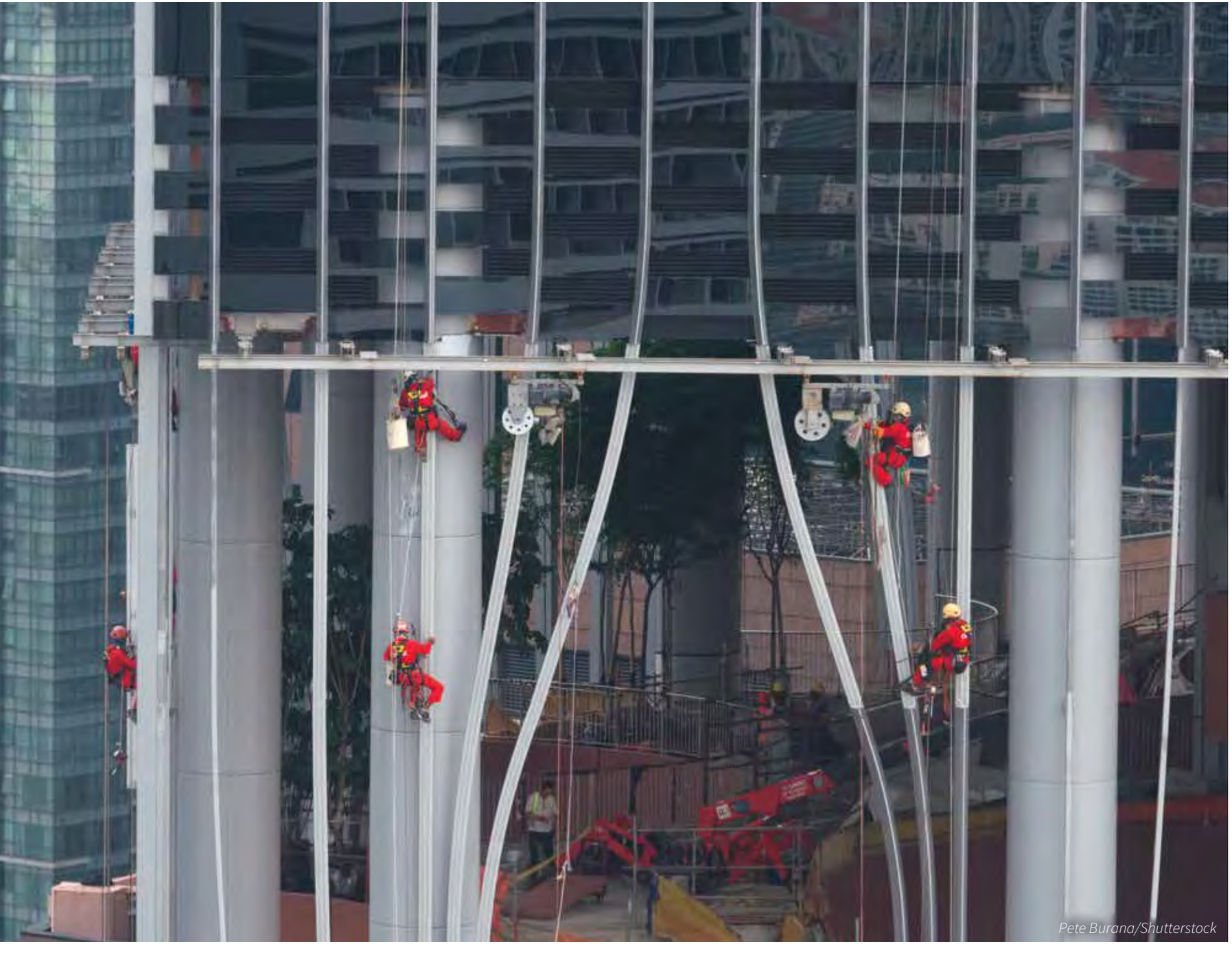
INSTITUTE FOR THE PUBLIC UNDERSTANDING OF RISK

Misinformation and disinformation threaten safety. They add to the challenges facing people as they assess the risks they take in their daily lives. They increase anxiety. When people's well-being is threatened by digital media, it is more important than ever to help them make properly informed decisions to reduce risks and save lives. There is an imperative need for clear, consistent, credible and reliable information from trusted sources if people are to avoid being drawn to dubious outlets.

If people are to feel the world is a safer place, the gap between public perception and real-world risk must be reduced. Scarce resources are wasted by governments on alleviating worry rather than reducing analytical risk. A better public understanding of actual rather than perceived risk will feed through to better public policymaking. As the discussion of resilience planning has highlighted, a failure to prepare for infrequent events which have extreme consequences can be devastating. People who are better informed can better influence their own societies, minimise disagreement about risk and find solutions best suited to meeting what most people want. As the Lloyd's Register Foundation *Foresight Review on the Public Understanding of Risk* (2017) observed, better public understanding of risk 'should improve trust and contribute to inclusive growth for society at large'.

With the Foundation's objective of making the world a safer place, improving the public understanding of risk was one of its priorities. Perception of risk differs not only between individuals but also between cultures. While the topic has been thoroughly researched in the UK, for example, it had not been similarly addressed in Asia, which has 60% of the world's population. As mentioned above, in 2016, in partnership with the National University of Singapore, the Foundation endowed IPUR, the Institute for the Public Understanding of Risk.

Under Professor G.C. Koh, IPUR seeks to narrow the gap in understanding through research, education and outreach, based on three priorities: environment and climate; data and technology; and health and lifestyle. These cover many of the major global safety challenges already identified by the Foundation. The Institute chose its initial projects, working in partnership with local organisations, for the positive impact they would have on communities.



Pete Burana/Shutterstock

LEFT *IPUR research is developing a methodology for identifying climate-related risks in Singapore workplaces which can be applied to the construction industry, to other sectors and other tropical cities.*

Environmental projects relating to Kathmandu and Jakarta have already been mentioned (see pages 118 and 144) as has the project on reducing the fear of risk in Mongolia.

The Institute is also carrying out fundamental research, following up work done in the 1980s, on the role emotion and experience play in people's perception of risk. This will be tied to the risk from emerging technologies. One of the Institute's ambitions is to create a risk perception index for practical use at every level, local to national.

Perhaps the most important of the Institute's initiatives is the development of the concept of risk know-how. As the Foundation put it at the time the Institute was launched, its aim was 'to promote good science, good debate and good evidence'. This has been furthered through the Foundation's partnership with the independent charity Sense about Science. Risk know-how, as defined by the international Risk Know-how project, 'is about informed decision-making. Every risk entails a trade-off with the benefits and costs of action or inaction, and we weigh these up to make a decision.' Raising public awareness in partnership with key agencies is a vital part of this work, which is helping to address the problems of misinformation and disinformation.

Joshua Sukoff on Unsplash

LEFT AND OPPOSITE
Having risk know-how equips people to weigh up claims and data about risk in the way that works best for their circumstances and the discussions they are having in their communities.


Fermin Vázquez Contreras/Thinkstock

THE CONVERSATION

Countering misinformation was also the reason for the Foundation's decision to support the appointment of a science editor for the online open-access, not-for-profit magazine, *The Conversation*. Founded in Australia in 2011, and launched in the UK in 2013, *The Conversation*'s professional team works with expert researchers in universities and other institutions, drawing on their knowledge for dissemination to the wider public. As a counter to fake news, *The Conversation* aims to rebuild trust in journalism, as its website states:

> 'Access to independent, high quality, authenticated, explanatory journalism underpins a functioning democracy. Our aim is to allow for better understanding of current affairs and complex issues. And hopefully allow for a better quality of public discourse and conversations.'

The Foundation's support enabled *The Conversation* to increase its coverage of science, technology and engineering. *The Conversation*'s global network now draws 21.5 million monthly users, with a total monthly audience of 64.2 million including through republication in other channels.

ABOVE *A 2018 article commissioned by* The Conversation *looked at 'Why 50,000 ships are so vulnerable to cyber-attacks'. The authors found that the shipping industry had been slow to prepare cyber-security but that this had provided the opportunity to learn from other sectors and fully understand risks.*

ABOVE *The World Risk Poll provides the first ever complete picture of the differences between people's perception of risk and their experiences of those risks.*

WORLD RISK POLL

Developing robust evidence for better experience and perception of risk and safety issues was the purpose of the pioneering World Risk Poll, carried out by Gallup and funded by the Foundation. The first poll in 2019 gave a voice to millions of people for the first time on risk and safety, filling a crucial gap in global data. It covered more than 150,000 people in 142 countries, in some of which such evidence was at best scanty and often non-existent. As the first of its kind, to all those involved in the world of work the poll gives freely the information they need to take the right measures to improve the safety of workers. In the words of Joaquim Paulo Pintado Nunes of the UN International Labour Organization (ILO):

> 'This is the first time that we have heard the voices of ordinary workers from across the world, talking about the risk to physical and mental well-being they face in the workplace.'

The 2019 poll focused on risk and safety in people's daily lives. It has been an invaluable resource for research into diverse areas, including the perception of the risks relating to misinformation. In April 2022, for instance, the Shorenstein Center on Media, Politics and Public Policy at the Harvard Kennedy School in the USA published a paper on the subject drawing on the findings of the 2019 poll. This focused on the perceptions of internet users on the risks associated with misinformation. Researchers concluded that 58.5% of regular internet users worldwide were anxious about the risks, with most concern among the young and low-income groups. The degree of anxiety varied significantly: regionally, concern was highest in Latin America and the Caribbean (74.2%) and lowest in South Asia (31.2%), while in individual countries concern was greatest in Malawi (87.4%) and least in Lithuania (26.4%). The study established that education is important in enabling people to appreciate the threat from misinformation. Cultural differences between countries were also thought to explain differences in people's attitudes. Unsurprisingly, in undemocratic nations, where media is state-controlled, people were much

less aware of the dangers of misinformation, compared with people living in countries where access to media is uncontrolled.

A second poll, constructed with input from organisations such as the ILO, UN Disaster Risk Agency and the World Bank, took place in 2021. Although the pandemic meant the poll was smaller, the data gained from it has made it possible to devise three risk indices. The World Worry Index covers people's perceptions of everyday risks, such as severe weather, violent crime and threats to well-being; the Experience of Harm Index looks at the extent of harm experienced by people every day; and the Government Safety Performance Index records whether people trust their governments to keep them safe.

The poll helps organisations to take action tailored to meet the concerns of people in different parts of the world. For most people, their main anxiety was the impact of severe weather. For more than half of all internet users, fake news was their major worry. More people were concerned in low-income countries where social conflict was aggravated by fake news. The poll also showed, however, that a significant minority of internet users were unaware of the risk of disinformation and misinformation. This underlined the need for other steps to counter this threat and to help people obtain reliable information from trusted sources.

LEFT *For the 2019 poll 150,000 people were interviewed, most face to face, including in some of the most remote and challenging parts of the world.*

Deela Dee/Shutterstock

ABOVE *A recent report by the Foundation's Evidence and Insight Centre provided insight about incidents and accidents at sea.*

EVIDENCE AND INSIGHT

The Foundation's ambition to build the best evidence and insight available to understand the complex factors that affect safety, and what works to reduce harm, led to the creation of the Evidence and Insight Centre in 2019. Led by Dr Sarah Cumbers, the Centre aims to make the world a safer place by supporting the application of evidence and insight to safety challenges. The Centre also gathers evidence of the impact of the work funded by the Foundation. As an example, the Centre's recent review of published data on incidents and accidents at sea identified new avenues for further investigation. The Centre also collaborates with organisations around the world, which can amplify its work, such as the US National Safety Council.

Imran Usted/Lloyd's Register Group

CHAPTER 6:
A FAIRER, SAFER WORLD

In a time of turbulent change affecting the lives of billions of people, the contribution of the many organisations working towards a fairer world becomes even more vital.

LEFT *In 2016, UNICEF reported that girls and women spend 200 million hours a day gathering water. To solve practical problems, like the lack of fresh drinking water, engineering skills need to be developed for a fairer, safer world.*

Arne Hodalic/Corbis Documentary via Getty Images

ABOVE *Care is needed to ensure that utilising technology to tackle global challenges does not have inadvertent adverse consequences. For example, extracting minerals for electric vehicle batteries has been linked with the degradation of the environment.*

Decarbonisation and the digital and data revolutions, the two main challenges of our time, will transform how we live. The world will be a different place. Yet the cost of making the transformation should not fall on those least able to afford it, wherever they live. Technology is our ally in implementing decarbonisation.

But we must be careful that utilising one to solve the other does not have inadvertent adverse consequences. For example, mining the minerals such as cobalt, lithium and nickel used to create the batteries for the electric vehicles taking over from those fuelled by petrol and diesel has been linked with the degradation and pollution of the environment and with human rights abuses.

Action to tackle climate change must surely strive to improve social equality in the process, so that imposing a carbon tax on vehicle users must be matched by improving public transport. Carbon border taxes, currently under discussion, must be designed to ensure they do not penalise developing countries. The benefits of emerging technologies must be equally shared and the most vulnerable protected from their disbenefits. For instance, a devastating report on Digital Welfare States and Human Rights from the UN special rapporteur on extreme poverty in 2019 revealed how AI and other technologies are being applied in many nations to target, monitor and disadvantage the poorest in society. The push by governments around the world to make the most of their interaction with citizens online takes no account of the millions without access to the internet or the skills to use it. Yet the same report stressed how digital technology can be used to help people improve their lives.

While the Foundation is funding various projects utilising technology to enhance safety, it recognises that one of the most important ways of helping people to cope with these challenges is by giving them the education and training they need to open up new opportunities. The Foundation also understands that this should be coupled with efforts to keep people safe at work, either by materially improving working conditions or by putting in place effective enforceable regulations.

EDUCATION AND TRAINING FOR A FAIRER, SAFER WORLD

People need resilience to face a more uncertain world. Through education and training, they can make their lives safer and their futures more secure.

In Southeast Asia, one of the most populous parts of the world, 124,000 people are injured at work every year in the region's fastest growing economies, which can often leave individuals and their families destitute. In a region investing heavily in infrastructure development, with construction a major employer, poor welding is a frequent cause of accidents, whether a slipped welded joint, shifting steel girder, cracked pipe or moving structure. One of the problems is that many countries in the region lack sufficient trained engineers to create safer working environments and save lives.

In 2018, to tackle this deficiency, The Welding Institute (TWI), with support from the Foundation, launched the Southeast Asia Skills Enhancement Programme (SEASEP). Through short, practical courses, SEASEP has since trained more than 4,000 people as welders and inspectors. Over 1,800 people have gained international qualifications. For many participants, the achievement has been life changing. But the programme, organised in partnership with local communities to ensure its future, has had a wider impact. It has secured the greater influence of a new generation of qualified engineers, their greater employability and better safety standards.

Educational Volunteers Foundation of Turkey

ABOVE *Education and training, such as the Science Firefly project in Turkey (see page 263), can help make sure the benefits of emerging technologies are shared equally.*

OVERLEAF *In Southeast Asia, poor welding is a frequent cause of accidents. SEASEP has trained more than 4,000 people as welders and inspectors.*

Basicdog/Shutterstock.com

More than half of those taking part were women, encouraged to join through the availability of bursaries. For Aamir Khalid, TWI's Chief Executive, watching the training videos featuring many of those women is an emotional experience:

> 'Because we have changed their lives … you know that maybe some of those women wouldn't have had a good chance in life. Not only are they doing something they love, they are breaking into a man's world, and that is always pleasurable to see: that you can have a woman welder on site, that gives me great pleasure.'

With engineering in high demand in developing parts of the world, encouraging the interest of young people in the field and giving them the necessary skills not only offers them a long-term career, but strengthens engineering expertise in their own countries. The bursaries also bring science and engineering to less advantaged students.

TWI Ltd

Educational encouragement is crucial in fostering a love of science, technology, engineering and maths in students at an early stage. In parts of China, South Africa and Brazil, the UK's National Space Academy (NSA), supported by the Foundation, is doing just that through a series of pioneering projects. In China, for example, the NSA worked with the China National Space Administration and the Global Science and Innovation Network, bringing space science to life in the classroom. It is also working with the United Arab Emirates as part of a drive to improve the education of less advantaged young women at school and undergraduate level and to motivate them to take up science and engineering.

The Educational Volunteers Foundation of Turkey (TEGV) has taken scientific education and extracurricular activities to more than 2 million children in the more remote parts of the country since it was established in 1995. Since 2015, with funding from the Foundation, it has been using the Science Firefly mobile learning unit to enthuse children. As one young student, Ibrahim, related, 'I've done experiments I never did before in this Science Firefly. I used virtual reality goggles. I created holograms.' Once again, TEGV's aim is to stimulate increased and more diverse participation in science and engineering, strengthening the country's scientific expertise.

The pandemic has accentuated the need for more engineers. In the global south, for example, their skills are vital in meeting the need for suitable shelter, clean water, sanitation and energy. In some instances, scholarships are available at institutions in the developed world. The University of Manchester's Equity and Merit Scholarships, supported by the Foundation, offer graduates from countries such as Ethiopia, Malawi, Uganda, Tanzania and Rwanda the chance to advance their engineering and technological education.

OPPOSITE *More than half of those taking part in SEASEP courses were women, encouraged to join through the availability of bursaries.*

Knowle West Media Centre

OPPOSITE *UCL's Making Spaces aims to empower young people from under-resourced communities.*

Even in developed countries, engineers are in short supply. The NSA's UK programme uses space science to inspire school students to make progress in core science subjects. One of its achievements was designing the experiments in physics and chemistry delivered by UK astronaut Tim Peake during his time on the International Space Station. Thanks to funding from the Foundation, the NSA expanded its programme from 4,000 students and 300 teachers in 2013, to 7,000 and 1,000 respectively in 2018. The NSA also developed a post-16 space engineering course in partnership with Loughborough College. Many students have come from non-traditional engineering backgrounds. Most of them carried on to university or higher apprenticeships with leading engineering companies.

The Making Spaces project, run by University College, London (UCL), also funded by the Foundation, has made use of the makerspaces concept, which develops collaborative, hands-on learning for young people through informal, multi-purpose workshop spaces. UCL has adapted it to inspire wider, more inclusive participation in science, engineering and maths education. The scheme fosters the creativity of those taking part. For instance, one young designer came up with a practical, attractive, fold-up backpack bed for the homeless, illustrating how science and engineering can be used to wider social benefit. The Foundation also joined with UCL's Centre for Engineering Education to launch its Innovations in Engineering Education programme in 2018.

Another organisation offering support to young people from diverse backgrounds entering engineering is the Institute of Engineering and Technology. The Institute's Engineering Horizons Bursary, backed by the Foundation, supports young men and women who would otherwise struggle to fund their education. Foundation grants also support 20 of STEM Learning's ENTHUSE Partnerships, which bring together students, schools and colleges, and industry to deliver quality engineering education.

Engineering skills are also scarce in the maritime industry. Bodies like the Shipwrights' Company are playing their part in filling this gap and extending opportunities for young people through apprenticeships. Inspiring young people to consider a future in marine engineering is one of the objectives of the STEM and the Sea programme run by the Tall Ships Youth Trust. Every year the programme gives a group of less advantaged young people the chance to experience life at sea on a sailing ship.

The invaluable historic archive of the Foundation's Heritage and Education Centre is being exploited to encourage young people to take an interest in science and engineering. In partnership with the 1851 Trust, an educational charity, the Centre's material is being used to illustrate the links between archives, engineering innovation and contemporary challenges. For example, sport and science come together through records relating to the history of Britain's America's Cup yachts. The Foundation is ambitious to develop the Centre as a global resource for understanding engineering and technological innovation and its impact on society.

In recent years, efforts have been made to attract potential engineers from a wider range of social backgrounds. Despite years of effort to increase the profession's diversity, many sections of society are under-represented, from women and transgender people to the disabled and those with working-class or ethnic-minority backgrounds. Making engineering more diverse is a challenge taken up by the UK's Royal Academy of Engineering. The Academy's Engineering X international programme brings together experts from around the world to offer participants a more inclusive, sustainable and safer future.

For the Academy's Chief Executive, Dr Hayaatun Sillem, diversity has proven advantages. Diversity of thought, for example, brings creative solutions to problems. An inclusive culture makes everyone feel welcome, able to speak up, share concerns and contribute to the full. The Foundation, as the Academy's partner, shares this commitment, recognising that greater diversity and inclusion results in better health, safety and sustainability. Engineering not only offers valuable employment to many young people and gives them the skills needed in a changing digital world; as an essential part of any plan to make the world a fairer, safer place, it also helps them to solve practical problems like air pollution, the lack of fresh drinking water and expanding the supply of renewable energy.

By enhancing engineering education, Engineering X, like SEASEP, will strengthen expertise, reduce industry fatalities and improve safety. A survey commissioned in 2019 by the Royal Academy of Engineering into the state of engineering in 99 countries revealed that better education and professional training were a priority. The Academy responded by funding a range of projects, through the Engineering X programme, across 14 countries across Africa, Asia, the Middle East and South America. In Ghana, Engineering X supports the National Youths in Cybersecurity, Technology and Engineering Project, which is meeting the growing need for cyber engineers. In Nepal, support from Engineering X has helped to build a team at a new FabLab, a digital fabrication laboratory, helping students to develop their engineering skills and turn their ideas into reality. In Indonesia and the Philippines, students are using virtual reality to learn about process safety. In six low- and middle-income countries, the Academy is supporting 25 Safety Champions in Engineering Education, who will act as advocates for their discipline.

ABOVE *With support from Engineering X, the Nepal FabLab provides a range of courses and workshops to diverse participants – young engineers, entrepreneurs, industrial product designers and students.*

Richard Walls/Stellenbosch University

LEFT *In South Africa, the Fire Engineering Education for Africa programme has set up two fire testing labs to help train consulting engineers in fire safety.*

In South Africa, there is an urgent need to train more consulting engineers in fire safety. Without any university training in the subject, fire safety engineering had a low priority. Yet the nation is industrialising, its population is growing, its cities, townships and informal urban settlements – housing illegally built on municipal land as homes for much of the country's impoverished people – are expanding. All these create greater risks. A single fire in an informal urban settlement can leave as many as 10,000 people homeless.

With funding from the Foundation, this gap is being filled through the Fire Engineering Education for Africa programme, initiated by Professor Richard Walls of Stellenbosch University. Organised in partnership with universities in Kenya, Namibia, Nigeria and Zambia, it is Africa's first postgraduate course in fire safety engineering. It also awards PhD bursaries for related research with students taking part from Ethiopia, Nigeria and Namibia. A pioneering textbook, *Fire Safety Guidelines for Informal Settlements*, based on research co-funded by the Foundation and edited by Walls, was commissioned by the South African government. Since its launch in 2016, the initiative has provided training for 200 fire safety engineers through industry courses. Two fire testing labs have been set up in South Africa, one by a consultant engineer trained through the project, illustrating the influence they are beginning to have. A national scorecard on fire infrastructure has been developed. The programme's long-term objective is the regional expansion of educational opportunities in fire engineering.

Giving people the expertise to influence their world is the purpose of the IMO International Maritime Law Institute (IMLI) based in Malta. IMLI was founded under the auspices of the International Maritime Organization (IMO) in 1988. It has been supported by Lloyd's Register since 1992, and the Foundation and its predecessor have funded three scholarships every year since 2002.

Taking talented individuals from developing countries, IMLI gives them the knowledge and the skills through its postgraduate scholarship programme to make an impact on maritime policy in their own countries. The programme is invaluable since the implementation, interpretation and application of international maritime treaties relies on individual nations, many of which have lacked the capacity to undertake the task.

In 2017, for instance, Donnette Streete, a senior civil servant in the Guyanese government, began studying for a postgraduate degree in international maritime law. Guyanese maritime legislation had been framed prior to the country's boom in oil and gas. The question was how best the country could simultaneously retain its strong environmental reputation and help shipping and fishing to prosper, while reaping the benefits of the oil and gas boom. Subsequently, Donnette Streete became Guyana's lead negotiator for the Intergovernmental Conference on Marine Biodiversity of Areas Beyond National Jurisdiction. 'None of this would have been possible,' she said, 'without IMLI and the Foundation. Our seas will be cleaner and safer because of the Foundation's support.'

RIGHT *IMLI graduate, Donnette Streete has played a key role in establishing a National Oceans Council in Guyana. 'The course gave me the skills to protect our marine environment and help different maritime industries to co-exist safely.'*

Fidal Bassier/Lloyd's Register Foundation

Another scholar, Simon Kofe, made an impassioned speech to COP26 as Tuvalu's foreign affairs minister, while standing knee-deep in water to highlight the threat climate change poses to the island.

Since 1988, 1,001 maritime officials from 149 states and territories have graduated from IMLI. Of these, 446 are female, with IMLI reserving half the places on every course for women. The Institute is committed to the IMO's programme for eliminating barriers which hinder the employment of women in maritime industries. But, as Director, Professor David Attard, notes:

> 'Despite the success of the IMLI policy to encourage the participation of women in the maritime sector, much more needs to be done. We need to promote the engagement of women in shipping managerial positions, in law and policy responsibilities. The fact that, in 2021, we are still trying to bring down barriers for women means that we have not done enough.'

Educating women has multiple benefits, not only for women themselves, but for society in general. Education helps to take people out of poverty. Educated women marry later and have fewer children, making a greater economic contribution. They can also make choices that reduce carbon emissions and strengthen community resilience against climate change. It has been estimated that better education for women worldwide could reduce GHG emissions by 51.48 gigatons by 2050. Research has also shown that expanding education for girls could reduce population growth by 2 billion by 2045.

An outstanding example of what can be achieved includes SEASEP, mentioned earlier (see page 258), which is giving women in Asia the opportunity to achieve independence by gaining employment qualifications. Another instance is the seaweed industry which in most developing countries employs more women than men. Harvesting seaweed depends on tides, requiring flexible working, which suits women well. Moreover, input costs and capital requirements are low. In Africa, significantly more women are employed than men, whereas the gender balance is more equal in Southeast Asia. The 'seaweed women', as they have been called, have played a leading role in advancing the sustainability of commercial seaweed cultivation for more than four decades. Their commitment, determination and resilience has made them the driving force of the industry, they have taken influential positions in their own communities and they have raised their family living standards.

The pan-African Campaign for Female Education (CAMFED) has been transforming the lives of women and girls in rural sub-Saharan Africa since 1993. Since then, it has supported the education of nearly 4.9 million girls in Ghana, Tanzania, Malawi, Zambia and Zimbabwe. It has an association of nearly 178,000 women leaders educated with its support and more than 308,000 champions advancing the cause of women and girls in their communities. By empowering women, CAMFED's work delivers social justice, fosters diversity and inclusion, reduces poverty and combats climate change.

RIGHT *'I'm living proof that female engineers can now achieve whatever they want to achieve,' says Vina Nanda Garjati, Lecturer in Mechanical Engineering, Jakarta State Polytechnic – one of the first women to graduate from SEASEP.*

OVERLEAF *In Africa, the 'seaweed women' have played a leading role in advancing the sustainability of commercial seaweed cultivation for more than four decades.*

Muhammad Fadli/Lloyd's Register Foundation

Nowaczyk/Shutterstock

MAKING TRANSPORT SAFER

A better understanding of human performance is vital in achieving greater safety in transport, since human actions are involved in 70–80% of all transportation accidents. Road accidents, for example, kill 1.35 million people every year. For Professor Arnab Majumdar, Director of the Transport Risk Management Centre at Imperial College, London, funded by Lloyd's Register Foundation, the human factor is at the heart of safe transport. Making transportation safer is a constant challenge with immediate rewards in terms of lives saved and economic losses stemmed.

> 'Whether we're studying buses in Taiwan, trains in the UK or planes in Canada, it's clear that culture and human behaviour are increasingly important aspects of protecting lives and property.'

The Centre has covered every aspect of transportation from buses, cars and motorcycles to planes and trains, pioneering studies of the links between human behaviour and technology. For instance, the Centre has studied the impact of workload and fatigue on individual behaviour. In Taiwan, the Centre has been working in partnership with Taipei Medical University on how fatigue among bus and taxi drivers creates unsafe behaviour. Using wearable technology, experiments have measured physiological patterns over the same routes over time to compare performance against fatigue. Where poor sleep has affected performance, individuals have been offered support and advice.

Sam Barker Photography/Lloyd's Register Foundation

LEFT *'More than ever before, how people behave is at the heart of safe transport', Professor Arnab Majumdar, Director of the Transport Risk Management Centre at Imperial College, London.*

Top Photo Corporation/Alamy Stock Photo

ABOVE *How fatigue among bus and taxi drivers creates unsafe behaviour is being researched in Taiwan.*

In Australia's vast and sparsely populated Northern Territory, a similar study by the Centre focuses on the risks incurred by rural health workers on the lengthy journeys they must make in intense heat and dusty conditions when a breakdown can leave them stranded and undetected for several hours. The study aims to discover whether the uncertainty of such journeys can be removed, thus improving the continuity of rural health provision, by applying technology that will identify in real time when drivers are suffering stress, pinpointing their location and transmitting the data to allow immediate action. There is potential to apply the same techniques in other regions and countries, helping to change people's lives for the better.

RIGHT *A study in Australia's Northern Territory is focusing on the risks faced by rural health workers on the long journeys they must make in extreme conditions, and where breakdowns can leave them stranded for many hours.*

Travelling.About/Shutterstock.com

One of the Centre's students, Stavros Sidiropoulos, has developed his research into improving the environmental impact on communities living under or close by flight paths into a commercial venture. Vianair Inc., supported by the Foundation, specialises in improving the flow of aircraft around airports. As well as the environmental benefits, more efficient flight planning also contributes towards more sustainable aviation. In the USA, many airports struggle to incorporate all the appropriate factors in assessing aircraft flow because of the ageing software they use. The failure to consider the impact on local communities has often given rise to lengthy and costly court cases, delaying changes or forcing their cancellation. Vianair considers all these criteria, including safety, noise and environmental impact, from the outset, consulting local communities in advance to hear their concerns and alleviate their anxieties. The company is developing its software to handle other airport operations, such as changing the taxi network of an airport or adding a runway, which will assist operators in making investment decisions and maximise efficiency while maintaining safety.

New arrival procedures implemented by the Federal Aviation Authority (FAA) for Washington's Ronald Reagan Airport led to complaints and concerns from the local community. Vianair teamed up with consulting firm ABCx2 to revise the procedures and distribute noise levels more evenly among the involved communities (Arlington, Montgomery, Fairfax Counties and DC). Vianair and ABCx2 consulted all the interested parties, who could watch Vianair designing the procedure, using advanced graphics, and gain an understanding of the parameters involved, what would and would not work, and see the impact of proposed solutions over the wider area. The revised procedures won the unanimous approval of the communities immediately affected as well as those nearby, who were able to see how the noise impact had been equitably shared.

Russ Schleipman/The Image Bank via Getty Images

OPPOSITE *Vianair's software platform helps airports reduce emissions, noise pollution and delays while improving safety.*

SAFER WORKPLACES

The data on safety at work from the World Risk Poll showed two different worlds of work: poorer countries where millions earn their living from agriculture, construction and fishing, regarded as three of the most dangerous occupations; and richer countries where the biggest threat to the well-being of employees comes from workplace harassment and violence.

In low-income countries, 34% of farmers, farm labourers and fishers and 37% of workers in factories and on building sites reported suffering serious injuries at work. A typical response came from Ankit in New Delhi in India.

> 'We go into the field to work, anything can happen at any time, we can get injured, grievously with our equipment. We can get attacked by wild animals or catch an infection because of insects or we experience snake bites.'

According to the poll (see Chapter 5), 19% of workers worldwide had suffered serious injuries (as many as two-thirds in locations like Gambia, Malawi and Sierra Leone), while in some countries as many as half of all workers have been subjected to violence and harassment in the workplace. In both instances, significant numbers of workers endured poor mental health.

Revealing how the perception of risk often differs from the reality, the poll can help organisations explain true risks to their workforces. The Foundation, for example, alerted those engineers and inspectors who regularly drive a vehicle for their work about the real risks of driving that are often obscured by familiarity.

Katja Tsvetkova/Shutterstock

ABOVE *In low income countries, the World Risk Poll found that 37% of workers in construction and manufacturing were seriously injured at work; in East Africa this rose to 40%.*

Cultura Creative (RF)/Alamy Stock Photo

ABOVE *The World Risk Poll showed how men and women often perceive risk differently, yet the way risk is communicated rarely differentiates between them.*

The poll showed how men and women often perceive risk differently, yet the way risk is communicated rarely differentiates between them. This should encourage organisations to become more aware of gender bias, not only in the messages they put out about risk, but also in other areas of safety at work. Too much personal protective equipment, for instance, is unsuitable for women because it has been designed around the male frame.

Some of the Poll's findings created a sense of outrage. In some countries, such as Malawi and Swaziland, as many as three-quarters of female workers expressed anxiety about violence and harassment at work. Even in more prosperous nations, such as Finland, many women were just as concerned. Australia ranked sixth in the world for women who had experienced workplace violence and harassment, affecting 39% of women. This prompted an Australian human rights lawyer to create the Power to Prevent coalition of businesses committed to reducing this alarming statistic.

Australia and New Zealand saw the biggest gap between men and women citing crime and violence generally, 34% of women compared with 16% of men. The greatest anxiety over this issue among women was found in Latin America, the Caribbean and Southern Africa. The data contributed to a campaign by the UN International Labour Organization (ILO) to promote the ratification of the Violence and Harassment Convention, the first international treaty to address the subject. The Convention was adopted by the International Labour Conference in 2019 yet by the end of March 2022 it had been ratified by just 11 countries (Argentina, Ecuador, Fiji, Greece, Italy, Mauritius, Namibia, Somalia, South Africa, United Kingdom and Uruguay).

RIGHT *In most regions, more women than men named crime and violence among their biggest risks in the poll.*

Joseph Egabor8/Alamy Stock Photo

USING TECH FOR SAFER WORKING

Working in the energy industry is one of the world's most hazardous occupations with three-quarters of fatal accidents arising from a handful of highly risky activities. Like the shipping industry, the energy sector understands the need for collaboration in sharing data to combat accidents. Seven major companies commissioned the Energy Institute to develop a method of giving energy industry workers access to information to keep them safe. With funding from Lloyd's Register Foundation, the Institute devised a simple free app called Toolbox which uses stories about accidents and incidents to prompt workers about how to work safely. Launched in September 2019, continuously updated and available in ten languages, the app has been used by nearly 40,000 people in 180 countries.

Kostadin Luchansky/stock.adobe.com

Wan Fahmy Redzuan/stock.adobe.com

Toolbox is an app that shares key safety learnings with frontline workers in the high-hazard energy industry. All details are anonymised which encourages people to upload full and frank details of safety-related incidents they have experienced. It is available in several languages to reach a global audience.

Wan Fahmy Redzuan/stock.adobe.com

REGULATING FOR A SAFER WORLD

Regulations and standards, nationally and internationally, are a vital component for making the world a safer, fairer place. And a world transformed by digitalisation, data and climate change is a world seen differently by its people. Regulating the relationship between society, science and technology is increasingly complex.

While there has been progress in areas such as violence in the workplace, as the ILO Convention shows, in others international standards remain absent. Commercial fishing, one of the world's most dangerous occupations, is still unregulated in many countries. Shipbreaking is covered by the IMO's Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, adopted in 2009, yet more than a decade later it still needs to be ratified by countries representing 40% of world merchant shipping. Although governments around the world have been introducing their own legislation governing IoT security, there is still no single industry-accepted standard. An exception is the globally applicable standard for consumer Internet of Things (IoT) security released by the European Telecommunications Institute in 2019. As already noted, one of the challenges for regulators is keeping pace with the rapid development of new technologies that transcend national boundaries. For the future, this will often be work in progress.

Advances are being made. Under the auspices of the Assuring Autonomy International Programme (AAIP), for example, work on robots in manufacturing carried out by a team from the University of Sheffield, in partnership with the UK's Health and Safety Executive, will influence future regulation. With the same objective, the AAIP is also studying the many ethical implications of more sophisticated robotics. The Welding Institute's research on the structural integrity of safety-critical infrastructure is contributing towards the development of national and international standards. Recommendations from the Safe Seaweed Coalition are forming part of the first ever global food safety regulation for seaweed being developed by the UN Food and Agriculture Organization. The New Zealand-based, international not-for-profit FISH Safety Foundation (FSF) is working with the Pacific Islands to strengthen their regulation of the fishing industry with the aim of reducing illegal fishing.

M M Rahman/Alamy Stock Photo

ABOVE AND OVERLEAF *The ILO classifies shipbreaking among the world's most dangerous occupations but a 2009 IMO Convention that could help improve safety has yet to come in to force.*

Akhtar Soomro/Reuters/Alamy Stock Photo

Once again, part of the way forward, outlined in the Lloyd's Register Foundation's *Foresight Review of the Future of Regulatory Systems*, published in 2021, is better collaboration, sharing lessons already learned. The review used the Netherlands Delta Programme (see page 78), as an example of lessons learned from the past with present regulatory relevance. It showed how the behavioural sciences were influencing public policy in Singapore by researching how individuals think and make decisions. This began in a small way with interventions to help retirees review their options. The 'nudge' concept has been applied with varying degrees of success in several nations. The conclusion from Singapore is that it can be used most effectively as one element in policymaking, bottom-up rather than top-down.

Technology itself is being applied to assist regulators. In the UK, big data is helping government track back through centuries of legislation to develop a clearer view of future regulation for specific industries. Blockchain is being used to support better regulation of food sources and supplies. Advanced data analytics allows regulators to share information more effectively. The ability to analyse growing volumes of data, however, poses a challenge for regulators. Moreover, devising regulations and standards requires effective enforcement. Regulations are in place in many countries to ensure the safety of ferries, yet a thousand lives are lost every year in ferry sinkings, a safety challenge the Foundation is tackling (see Chapter 7). The issue of the tech giants, social media and fake news at the beginning of Chapter 5 shows just how difficult global enforcement can be.

In a world that often seems more polarised, more extreme, more fragmented, the repeated clarion call from the Foundation through its work for greater global collaboration is not just an optimistic aspiration; the projects it supports demonstrate what an effective approach this can be, producing practical and positive outcomes, improving the way we live and making our lives safer.

kandl stock/Shutterstock

LEFT *The application of behavioural sciences in Singapore public policy began with small-scale projects. Some of the nudges are remarkably simple. Shown here, train stations have green and red arrows on the platform indicating where you should stand to speed up the alighting process.*

Jcob Nasyr on Unsplash

CHAPTER 7:

SAFER, SUSTAINABLE OCEANS

A global commitment to take action against threats is needed to secure the future of our oceans.

LEFT *Tackling the challenges that threaten the oceans and developing the potential of the ocean economy are essential for the planet and human life.*

In February 2022, the One Ocean Summit was held in Brest on the Atlantic coast of France. One hundred countries committed themselves to measures to preserve the ocean from human harm, to reduce illegal fishing, to cut plastic pollution and to increase protection for international waters. As the US climate envoy, John Kerry, said, 'the ocean … makes life on Earth possible, produces more than half of the oxygen we breathe – and even that is at risk. The ocean and climate are inextricably linked.'

Yet, the future of our oceans, of the people living in coastal communities and of those who rely on the oceans for their living is uncertain. Human activity is depleting their once-abundant resources and polluting their waters, while climate change is raising sea levels, threatening crowded coastal communities and island nations around the globe. Tackling these challenges is essential for the planet. Covering 70% of the Earth's surface, the oceans are vital for human life. They give millions of people their livelihoods. They carry 90% of all our goods. According to Lloyd's Register Foundation's 2021 *Foresight Review of Ocean Safety*, subtitled 'Engineering a safe and sustainable ocean economy', the oceans contribute US$1.5 trillion to the world economy. As the world becomes more populous, and land-based resources diminish, they will become even more important. The ocean economy offers many of the answers to some of the world's most pressing problems, for example, as a source of protein-rich food, renewable energy and carbon sinks.

ABOVE *In addition to creating beautiful habitats, macroalgae such as kelp play a large role in reducing the effects of global warming.*

OVERLEAF *Salmon farm in Norway. The ocean economy offers many answers to some of the world's most pressing problems. Aquaculture is a valuable source of protein-rich food.*

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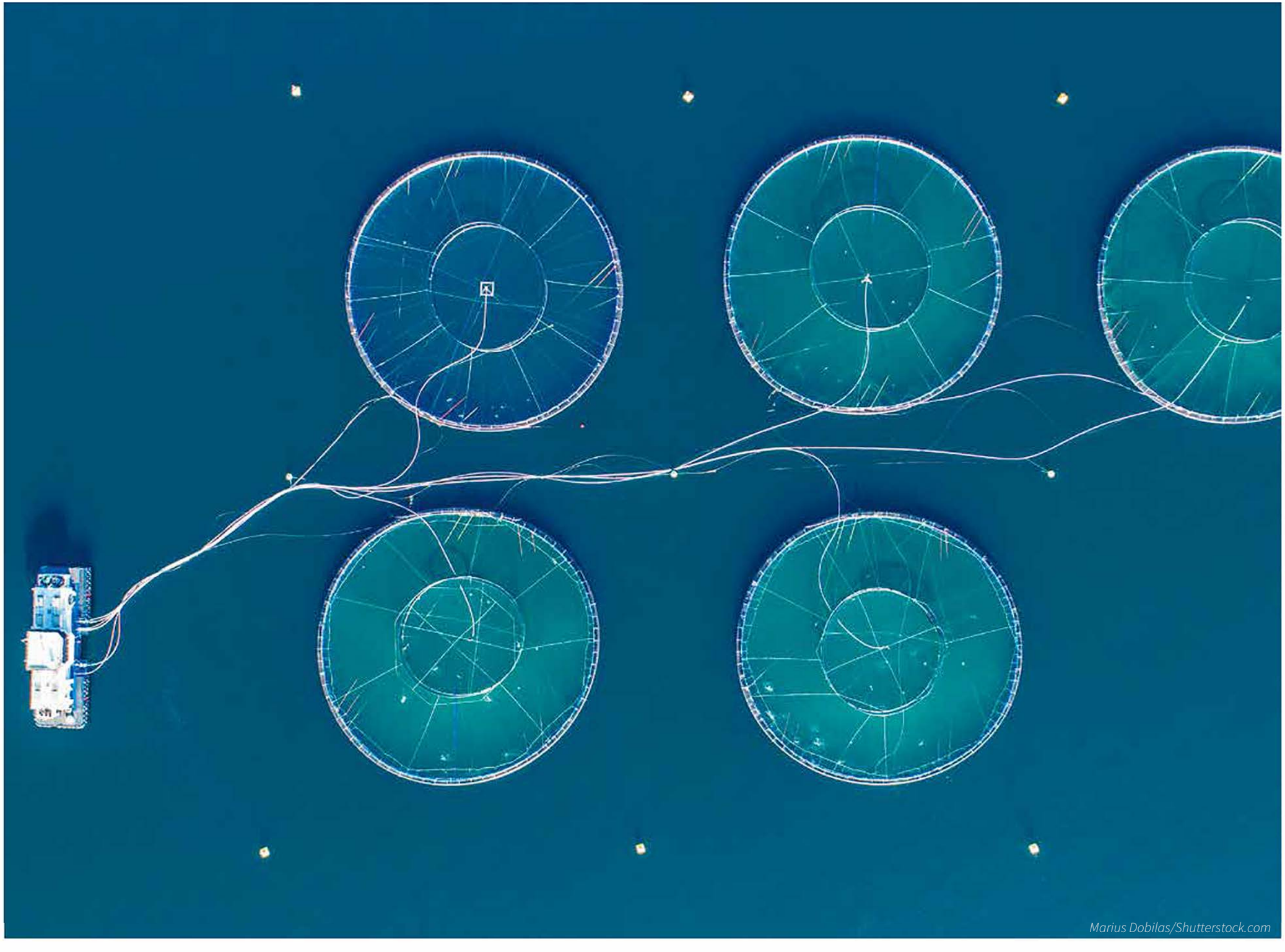


Marius Dobilas/Shutterstock.com

The oceans must be managed in a sustainable way that ensures their benefits accrue as equitably as possible. Effective regulation is crucial to protect their essential role in the planet's ecosystem. We must make sure that the oceans can meet the everyday needs of many millions of people while protecting their health, keeping them safe in their daily lives and securing a sustainable environment. Professor Mark Cassidy, writing the foreword for the Foundation's review, succinctly summed this up:

> 'Our oceans connect us, protect us, sustain us and regulate our weather and climate. Wherever we live in the world, we are deeply and powerfully connected to the sea. We are ocean citizens.'

The Foundation's interest in the oceans is rooted in the heritage of Lloyd's Register, the world's first classification society, established to ensure the safety of ships at sea. It is deeply committed to ensuring the sustainability of the oceans for the vital role they have in helping humankind navigate an uncertain future. This commitment is displayed in the Foundation's support for a diverse array of projects, from improving the working conditions of seafarers, fishers and shipbreakers, to continuing research into the safety of ships at sea.

Fuse/Thinkstock

OPPOSITE *The Foundation is deeply committed to ensuring the sustainability of the oceans for the vital role they have in helping humankind navigate an uncertain future.*

SAVING LIVES IN THE FISHING INDUSTRY

Fish provides the primary source of protein for the diets of almost 40% of the world's population. Global food stability depends on the millions of small-scale fishers who harvest the fish, yet in many developing economies, sea-fishing is a dangerous and precarious occupation. How many lives are lost every year is a matter of debate since little proper research has been conducted, but it is suspected to be tens of thousands more than the figure of 24,000 estimated since the mid-1980s. Many of the deaths occur in Southeast Asia, the heart of the world's fishing industry, home to most of the world's 36 million full- and part-time fishers and their 3.8 million fishing vessels.

Thanks to the FISHER project, led by FISH Safety Foundation (FSF), work is now underway to provide a more accurate figure for deaths in the industry. Supported by the Foundation, the project is compiling data from around the world for analysis. Collecting the data is difficult since it encompasses many different languages, many fishers lack literacy, there is often no connection to the internet and regulation and standards are absent in many developing countries. To overcome these barriers, a reporting app has been developed with a voice recording function, thus enabling a recording by a Bangla-speaking fisher, for example, to be translated into data. The knowledge derived will help to implement safety measures best suited to each locality.


FISH Safety Foundation

LEFT *The FISHER project aims to provide a more accurate figure for deaths in the fishing industry using a reporting app with a voice-recording function that can be easily used by fishers.*

OPPOSITE *Accident data collection from fishers by a researcher using the FISHER app.*


FISH Safety Foundation

According to a World Bank study in 2012, 120 million people worldwide rely full- or part-time on wild-capture fisheries for their livelihoods. Since a fisher's death at sea often spells hardship for families, raising safety standards not only saves lives but also gives fishing communities greater economic certainty. The Foundation's 2018 insight report on safety in the fishing industry had identified the three nations, Bangladesh, Indonesia and the Philippines, with the worst safety records. In these countries, safety at sea is often compromised by poor understanding of the risks involved, a failure to take note of weather warnings and unstable or poorly equipped craft. With support from the Foundation, the Pew Charitable Trusts and the International Maritime Organization (IMO), FSF worked to remedy this with the Memorial University of Newfoundland, in Canada. This quickly developed into a much bigger project, fishSAFE 2025, to help local communities set up their own safety training. While the first stage

FISH Safety Foundation

LEFT *Hasan Joy, FISH Safety Foundation, interviewing local people as part of the data gathering to improve safety for local fishers.*

of the project in Bangladesh went ahead, the Covid-19 pandemic forced the deferment of work in Indonesia and the Philippines.

One lesson learned from the project, said FSF's CEO Eric Holliday, was that 'You have to have the right people on the ground who are respected and have the ability to get results.' He had met Professor Sazedul Hoque from Patuakhali Science and Technology University in the south of Bangladesh. Well respected locally, Professor Hoque chaired the university's Department of Fisheries Technology and had good contacts in government. He had also trained many of the country's local fisheries officials. One of his students, Hasan Joy, came from a local village, which made him invaluable for carrying out research, obtaining information and sourcing local material.

A new Roadmap project is underway which aims to catalogue current work in the fisher safety field and guide the best combined course of action to maximise fisher safety improvement. A global network of groups and individuals passionately dedicated to solving this most devastating of all marine safety problems has been invited to participate in workshops and meetings to share ideas and explore how co-operation can bring the most benefit to fishers everywhere. The Roadmap is expected to continue until the fourth quarter of 2022. Its output will inform future Foundation funding decisions to help improve fishers' safety.

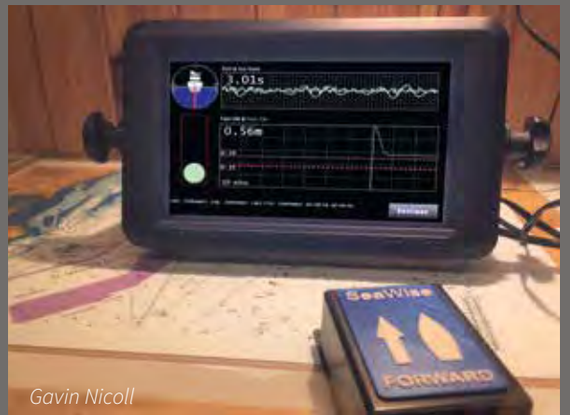
FISH Safety Foundation

ABOVE *Training, and simple interventions such as access to safe drinking water and life-jackets, can make a big difference to the safety of Bangladesh's fishing vessels.*

Sebastian Voortman from Pexels

SEAWISE

A major factor in the loss of vessels at sea is the inability to measure their stability. This deficiency is being redressed by a device designed to do just that, SeaWise, developed by Hook Marine with grant funding from the Foundation and a number of other organisations. Seawise gives an early warning of stability problems with a visual and audio alarm to alert the crew. The inventor, Kenneth Smith, is an engineer based near Troon in Ayrshire and director of Hook Marine. Through the Foundation's global network, he was also able to connect with others interested in the safety of commercial fishing, giving him the encouragement and inspiration to build on his own achievements. In 2020, for example, he was invited to speak to the UK's All-Party Parliamentary Group on Fishing Safety.



Gavin Nicoll

LEFT *Stability is a constantly changing factor in a fishing vessel as fuel and water are consumed and the catch is taken on board. The SeaWise monitor provides early warning of declining stability.*

Safety in the industry is also compromised by the ineffective policing of illegal fishing and the lack of enforceable standards governing fishing craft. In some coastal nations, illegal fishing brings with it slave labour and the mental and physical abuse of crew. An IMO convention on the safety of fishing vessels was agreed in 1977, although it has never been ratified, and it covers only vessels more than 24m long, which make up just 1.5% of the total global fishing fleet. Two-thirds of all fishing vessels are undecked, unmotorised craft less than 10m long. Holliday believes that the Foundation, with its links to LR as a leading classification society, can play a key role in securing enforceable international technical rules.

SAFER SHIPBREAKING

Shipbreaking is another dangerous maritime activity, with unacceptable levels of fatalities, injuries and work-related disease. This affects the poorest workers since 70% of ships are broken up on the beaches of India, Pakistan and Bangladesh. A serious work-related injury can be economically devastating for families. In the words of Hazel Ingham, Senior Manager for the Engineering X programme:

> 'With ships and other large offshore structures, the hazards are particularly acute in those parts of the world least able to manage them. While some do recycle responsibly, a dirty trade continues. Some rich nations export the problem of what to do with their old vessels and structures, and it is people on the Indian sub-continent who often have to clear up the mess and pay the price – in many cases with their health and sometimes with their lives.'

Sam Barker Photography/Lloyd's Register Foundation

ABOVE *Hazel Ingham leads an Engineering X shipbreaking programme: 'LRF's support means we're able to fund six projects that are using on-the-ground activities, research and community building initiatives to greatly improve safety and reduce the harm to people and the environment.'*

Todamo/Shutterstock

ABOVE *The well-being of crew is vital for safe shipping as human behaviour is a major factor in accidents at sea.*

Several projects supported by the Foundation are underway, from better training for shipbreakers to assessing the risk of failure in decommissioned offshore structures. One is identifying shipbreaking hotspots, another is developing industry standards in Southeast Asia, while a project led by the Sustainable Shipping Initiative is encouraging the voluntary disclosure by shipping operators of their decommissioning practices. Most shipowners that have joined the Ship Recycling Transparency Initiative go as far as imposing conditions on any buyers of its vessels to encourage responsible recycling. Ultimately, it is hoped to draw on these projects to devise enhanced industry safety standards and offer guidance on how best to prepare for the decommissioning of vessels and other marine structures. Efforts are also being made to encourage designers to make safety a priority when considering how vessels will be dismantled at the end of their lives.

SAFETY FOR SEAFARERS

Today's seafarers face challenges every bit as great as their predecessors. In an uncertain world – where climate change makes the oceans more unpredictable, technology makes the task of running ships more complex, and unusual events like the pandemic can leave crew isolated – seafarers need all the help they can get.

Since one of the biggest factors in accidents at sea is human behaviour, the well-being of crew is vital for safe shipping. Yet they are under constant pressure from stress and fatigue, poor pay and conditions, working in a competitive commercial environment on board vessels operated by increasingly complex systems. They can be at sea for as long as a year without a break. Even the largest vessels may have as few as 13 crew and consequently seafarers are forced to work unsustainable hours. Crews change frequently and their multi-national composition can create cultural and language barriers. On many new vessels, crew face less generous recreational facilities, restrictions on social activities and more crowded conditions. And every year some 2,000 seafarers lose their lives.

The pandemic has heightened the stresses of life at sea. Seafarers have found themselves far from their families in distant ports where they were forbidden to land, confined on board ship for months at a time. It

was estimated that in mid-2020 as many as 150,000 crew were trapped at sea, unable to be repatriated, as crew changes were suspended by several governments despite calls for them to be treated as key workers so that they could return home.

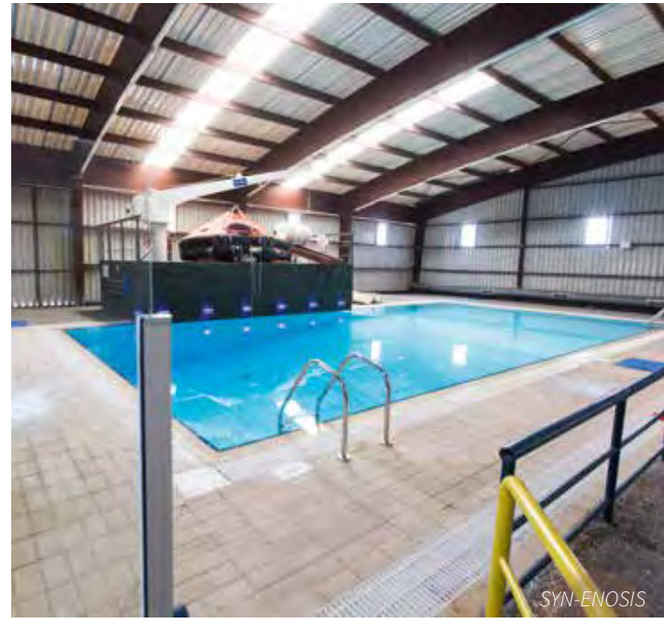
If stress affects crew well-being, and their capacity to do their job, then it endangers safety. When anecdotal evidence from charities and other organisations suggested that the pandemic was causing a spike in suicides among seafarers, the Foundation's Evidence and Insight Centre took an interest in the issue. An initial project with Nottingham Trent University explored the psychological well-being and safety of seafarers. In 2021 this led to further work based on confidential data-sharing between organisations to help the industry learn lessons from the pandemic for improving crew well-being and safety. The Foundation, in association with the Seafarers Hospital Society and Yale University, also took evidence from shipping companies about their own perspective on the mental health of seafarers, covering issues from training to living conditions.

In 2020, the Foundation supported a project investigating how better living conditions for crews can reduce the pressures of their daily routine. At Cardiff University's Seafarers International Research Centre, using data from around the world, researchers came up with practical recommendations for future crew accommodation and facilities. These range from better recreation facilities to simple things like improved lighting, more storage space and greater protection against noise and vibration.

Although employment practice affects crew well-being and safety, it has been the subject of very little research. In 2017, researchers at Southampton Solent University began a three-year project, 'The Effective Crew', funded jointly by the Foundation and the TK Foundation. They looked at the differences on vessels carrying 20 or more seafarers between 'fluid', that is, constantly changing, crews or retaining the same crew members. Existing research was complemented by the collection of data from an industry-wide survey. This concluded that fluid crews, as the practice is termed, had an adverse effect on welfare, safety and employment retention. Stable crews, in contrast, fostered trust and good working relations, and improved productivity and well-being, contributing to better safety. There were commercial

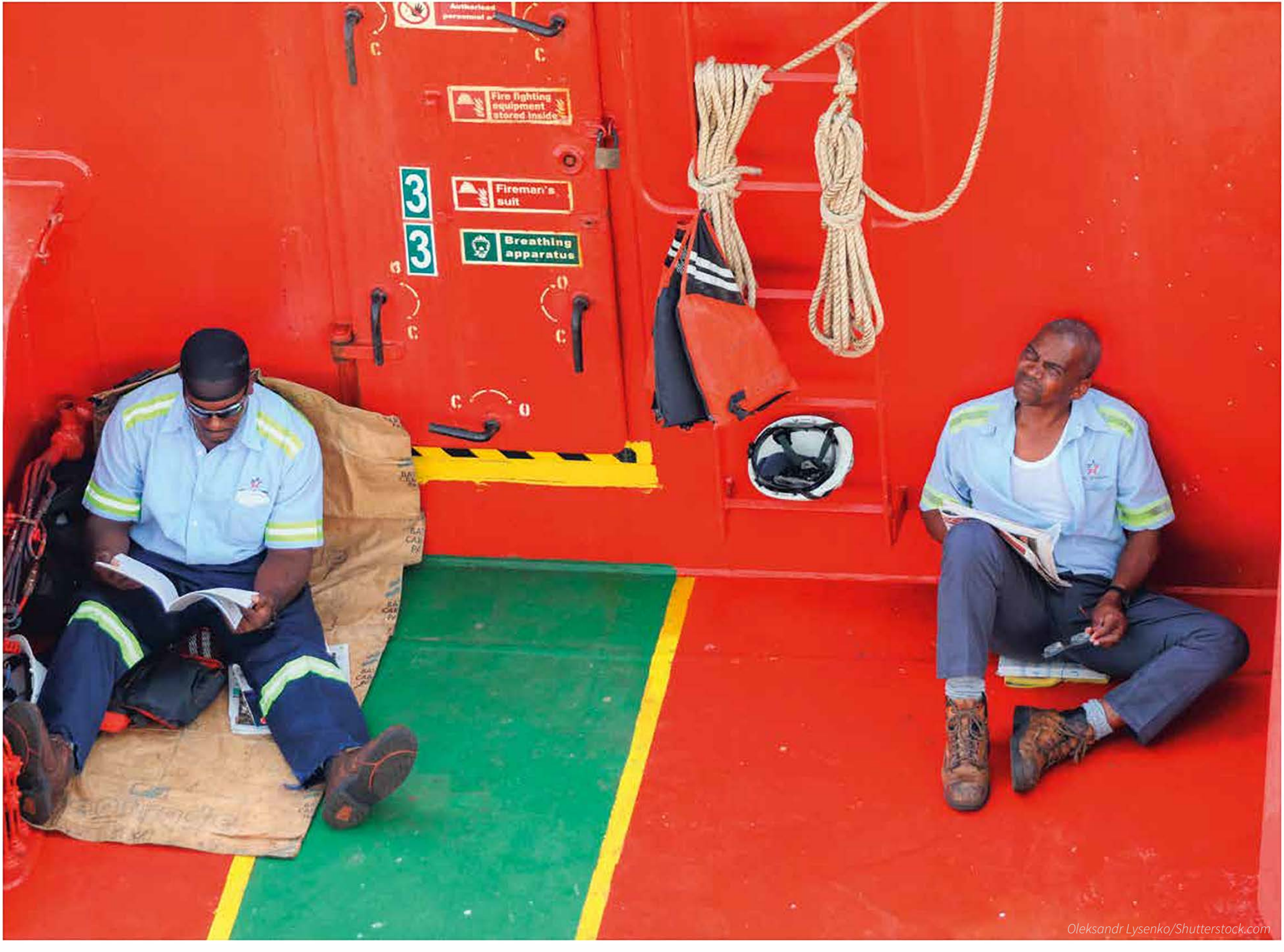
RIGHT *Support given by the Foundation to marine academies in Greece helped modernise training facilities, including this pool at the Merchant Marine Academy of Aspropyrgos.*

OVERLEAF *The well-being of crew can suffer on ships with less generous recreational facilities, restrictions on social activities and more crowded conditions.*



advantages, too, such as better maintenance standards, and thus lower maintenance costs, and shorter handover times.

As ships adapt to the challenge of climate change, and adopt more complex operating systems, up-to-date training is essential. The economic difficulties of the early 21st century left one leading maritime nation unable to maintain investment in training seafarers. The Greek merchant marine is the largest commercial fleet in the world, carrying around 20% of world trade, although like other maritime nations, many crew members are drawn from other nations. Training facilities in Greece suffered from a lack of funding during the country's recent economic downturn. Deteriorating buildings damage student morale and outdated training materials leave them ill-equipped for technological advances. With the help of a grant from the Foundation, the marine academies at Aspropyrgos, Macedonia, Chios and Kalymnos were modernised and equipped with the latest training facilities.



Oleksandr Lysenko/Shutterstock.com

SAVING LIVES AROUND THE COAST

Training is indispensable for the volunteer crews of the Royal National Lifeboat Institution (RNLI) operating around the coasts of the UK and Ireland. The RNLI's essential survival skills training was funded by Lloyd's Register Foundation from 2007 to 2020. During this time, some 4,000 volunteers were trained in Crew Emergency Procedures at the RNLI College in Poole. Their expertise helps save lives. In 2020, RNLI crews put to sea 8,239 times, helping 8,374 people and saving 239 lives.

In another project, in 2016 the Foundation funded radio operator training for 710 National Coastwatch Institution volunteer watchkeepers at 52 watch stations around the UK coast. Watchkeepers provide the eyes and ears along the coast, monitoring radio channels and providing a listening watch in poor visibility.

RNLI

ABOVE *May 2022: Helvick Head RNLI going to the aid of four sailors in the Gold Coast area of Dungarvan in the south-east of Ireland.*

RIGHT *In 2018, Foundation funding provided vital training for James Doyle and Simon Williams, volunteer crew members at Sennen Cove in Cornwall.*

RNLI/Tim Stevens

Investment in crew training is imperative, given that human factors are responsible for between 75% and 96% of marine accidents. In recent years, innovative accident reporting schemes have been established, such as HiLo (see page 180). Another is the Confidential Hazardous Incident Reporting Programme (CHIRP), which has been running since 2003. It allows seafarers to report safety hazards confidentially. Unsurprisingly, stress, fatigue and inadequate training rank among the most common causes of incidents. Analysed and anonymised, the data is shared with the industry to help raise safety standards. Backed by the Foundation from 2013, CHIRP has produced a guide on good decision-making for seafarers and created a team of ambassadors who make safety presentations to crew in several countries. During the pandemic, CHIRP campaigned for the recognition of seafarers as essential workers with access to the same travel rights.

In terms of accidents, the waters off the Southeast Asian coast, the Eastern Mediterranean and the Black Sea are the most dangerous parts of the world for shipping. Another voluntary reporting scheme for incidents and near misses was set up to cover the Eastern Mediterranean in 2021. The marine environment protection associations in Greece and Cyprus worked with LR to devise the scheme, which received funding from the Foundation. Shipping companies can anonymously report serious incidents concerning their ships. Sharing the information helps others to avoid similar incidents in the future. The associations also provide refresher training seminars, incident simulations and workshops on safety at sea.

Tim Cuff/Alamy Stock Photo

ABOVE *One critical element for those climbing on board a vessel at sea is the pilot ladder. In a CHIRP report a pilot said 47% of boarding arrangements he encountered did not meet required safety standards.*

SAFER SHIPS

Between 2011 and 2020, 876 vessels were lost at sea, including 348 cargo ships. As ships become larger, new construction methods are adopted, and the oceans are more frequently affected by extreme weather, constant research into how ships perform is essential for safety.

To give more certainty about conditions at sea in an unstable climate to seafarers – and others connected with the marine environment as well as coastal and other communities linked to the sea – the Global Network for Improving Prediction of Extreme Marine Events was established with Foundation funding in 2010. Based at Dalhousie University in Canada, the Network also comprised researchers from the universities of Melbourne, São Paulo and Southampton. It aimed to improve short-term weather forecasts, provide greater certainty over the incidence of extreme marine events in future decades, and make the results generally available.

The instability of ships, either in poor weather or due to loading, is one of the biggest risks to life at sea. When it became clear that the first rules laid down by the IMO governing ship stability were failing to prevent accidents on ships meeting the criteria, they were superseded by new IMO rules, finalised in 2020 but not mandatory. Instability can occur through human error. The *Golden Ray*, a car carrier, capsized off the coast of Georgia, USA, in 2019, resulting in losses of US$200 million. (This illustrates the greater commercial consequences arising from the loss of larger ships carrying more valuable cargoes.) The loss was attributed to inaccurate stability calculations made by the chief officer. And ships continue to capsize in adverse weather. In 2020, for

Darryl Brooks/Alamy Stock Photo

RIGHT *Instability caused the* Golden Ray *car carrier to capsize in 2019. In 2021, the salvage operation was estimated at US$842 million. It involved cutting the vessel into pieces using a floating crane.*

Jeom Kee Paik/KOSORI

OPPOSITE *Based in South Korea, ICASS has equipment that pits the materials ships are made from against the forces that cause catastrophes – explosions, fires, collisions and others.*

BELOW *Bulk carriers transport unpackaged bulk cargo, such as grain. Liquefaction – when a granular material transforms from behaving in a solid state to a liquid state – can affect the stability of a vessel.*

instance, the *Gulf Livestock 1*, carrying 6,000 cattle from New Zealand to China, capsized with the loss of 41 of the 43 crew and all the livestock during a storm in the East China Sea.

Research into improving ship stability is carried out at two international centres in the major shipbuilding nation of South Korea, at the Marine Hydrodynamics Laboratory of Seoul National University under Professor Yonghwan Kim and at the Korea Ship and Offshore Research Institute (International Centre for Advanced Safety Studies/ICASS) of Pusan National University under Professor Jeom Kee Paik. Their work has been supported by Lloyd's Register since 2008. This support proved instrumental in persuading the Korean government to invest £77 million in large-scale testing facilities at ICASS, seen as essential for testing the resilience of materials used in ship construction. In 2021 the Foundation offered additional support to permit ICASS to open these facilities to scientists and engineers from around the world.

Extreme instability in ships can also be caused by the liquefaction of solid bulk cargoes. This well-known phenomenon caused the loss of nine bulk carriers and the lives of more than 100 seafarers in the decade after 2010. In January 2015, for example, the Supramax carrier *Bulk Jupiter* sank in the South China Sea with the loss of 18 crew members after the

nektofadeev@gmail.com/iStock/Getty Images Plus

liquefaction of 46,000 tonnes of bauxite. In 2020, with a grant from the Foundation, Professor Susan Gourvenec and her team at the University of Southampton began research on improving the safety of bulk carriers. Their work generated unprecedented involvement from every sector of the industry, including marine architects, maritime lawyers, ship scientists, mining companies, testing laboratories and trade associations, all working towards appropriate protocols and devising a programme of research, education and communication. 'Everyone has commented,' said Gourvenec, 'how incredible it is that they had never all been in the same room before.'

Stability is at the heart of research into ship design at the Lloyd's Register Foundation University Technology Centre and the Southampton Marine and Maritime Institute based in Southampton. Under Professor Ajit Shenoi, scientists and engineers currently study three key topics affecting ship performance: understanding how hull shapes affect vessel's loads and motions; examining how materials can be used safely and reliably in ship construction; and exploring how to improve the operation of different systems within any vessel.

The poor safety record of ferries, in particular domestic ferries, in some parts of the world has been a source of concern for many years. On average, every year since the 1960s at least 1,000 people have lost their lives in ferry accidents. A significant proportion of these fatalities occurred in Bangladesh, Indonesia and the Philippines. There are many causes, ranging from a more

LaperladiLabuan/iStock Editorial/Getty Images Plus

LEFT *The poor safety record of ferries in some parts of the world has been a source of concern for many years.*

OPPOSITE *The FerrySafe project in the Philippines is identifying which measures have been most helpful in strengthening safety in its domestic ferry industry.*

Martin San Diego/FERRYSAFE

casual approach towards risk and the absence of regulations or their poor enforcement to inadequate training and substandard vessels. The Foundation identified the problem as a global safety challenge and commissioned a review of safety in the passenger ferry industry in 2018.

The Philippines, as an archipelago with almost 7,500 islands, is dependent on ferries for transport. For years poor seamanship, lax regulation and frequent overcrowding made it more dangerous to travel by ferry in the Philippines than anywhere else in the world. Since 2016, however, the industry has greatly improved its safety record, which has moved from worst in the world (number one) to eighth. The FerrySafe project is a partnership between the Foundation and Interferry, the international industry body. It is examining the reasons for this transformation so they can be shared with other developing nations. The research discovered that multiple factors were involved, including more effective regulations, better enforcement, the influence of insurance surveys and a ban on sailings in poor weather. Yet since the ferry industry in the Philippines is still characterised by a wide range of operators, from those running modern well-maintained vessels to others unable to afford the investment to make their substandard craft safe, more still needs to be done.

The same changing climate that is creating the more turbulent conditions threatening ferry passengers on the seas around the Philippines, is opening new routes for ships elsewhere. By 2050, it is expected a transpolar route might be possible through the middle of the Arctic. Some ships already carry oil and gas through the ice in polar seas. In 2020, orders for 15 ice-class vessels were placed to carry liquid natural gas from the Yamal Peninsula in Siberia to Europe and the Far East. Prior to the pandemic, because of rising demand for polar cruises, 28 new Arctic cruise-ships were scheduled for delivery before the end of 2022. Nevertheless, despite warming oceans, ice remains a danger in the area. As a result, with support from the Foundation, Professor Pentti Kujala and his team of researchers at Aalto University in Finland partnered other institutions through the Centre of Excellence for Scenario-based Risk Management in Polar Waters (CEPOLAR) to devise risk-based guidelines, issued in 2021, to help the shipping industry design safer ice-going ships.

A SAFER AND SUSTAINABLE OCEAN ECONOMY

The expansion of the ocean economy since the beginning of the 21st century has been so rapid it has been called the 'blue acceleration'. Containerships carry four times more goods every year than they did in 2000, supporting globalisation. More than 620,000 miles (1 million km) of submarine cables have been laid on the ocean floor to cater for expanding international communications. The generating capacity of offshore renewable energy soared from 100 gigawatts in 2008, 17 years after the first offshore windfarm, to 564 gigawatts by 2018. Global aquaculture production increased by more than 500% between 1990 and 2018. Despite climate change, oil and gas exploration has continued, while the growing shortage of onshore minerals stimulated a new industry, subsea mining, with more than 600,000 sq. miles (1.5 million sq. km) of the seabed so far leased for exploration. Blue biotechnology is exploiting the oceans as a sustainable source of biomolecules and biomass for a wide range of commercial uses, from food and fuel to pharmaceuticals. By 2030 it is estimated that 40 million people will be directly employed in ocean-related industries and more than three billion people will rely on the ocean for their livelihoods, the vast majority in developing countries.

ABOVE *Aalto University in Finland partnered other institutions to devise risk-based guidelines to help the shipping industry design safer ice-going ships.*

OVERLEAF *The expansion of the ocean economy has been rapid. By 2030 it is estimated that 40 million people will work in ocean-related industries.*


balipadma/Shutterstock.com

Adnan Buyuk/Shutterstock.com

ABOVE *A Foundation review of 2021 highlighted the challenges posed by the growth of the ocean economy.*

This growth poses numerous challenges. How can ocean space be shared equitably? How do we ensure new ocean industries such as deep-sea mining operate safely and sustainably? How do we secure a sustainable future for fragile marine biodiversity? As the Lloyd's Register Foundation *Foresight Review of Ocean Safety* (2021), led by Professor Mark Cassidy, put it:

> 'A just transition to a low carbon, sustainable ocean economy necessitates investment, education, infrastructure, innovation and decent, safe jobs.'

The review revealed, for instance, that large parts of the ocean economy, from aquaculture and mining to renewable energy, were often unregulated, with the implications that had for social equity and safety. 'It's a bit like the wild west in some areas,' Cassidy remarked.

One way forward is designing appropriate indices to help all those involved with the ocean economy make better decisions on safety and sustainability. The UN Global Compact and the Foundation are collaborating to create an Oceans Safety Index. By collating existing data and filling in gaps through research about the oceans, ocean activity and ocean industries, this will help investors, industry, governments and others gain a greater understanding of issues affecting safety at sea.

Industry collaboration is another way forward. The Safe Seaweed Coalition (see Chapters 2 and 6), is one example. Another is the Seafood Business for Ocean Stewardship initiative formed by 10 of the world's largest seafood businesses in 2016, which pledged to reduce illegal fishing, carbon emissions and discarded fishing gear. These are examples for other ocean industries to emulate.

Two-thirds of the world's publicly listed companies depend on a healthy ocean yet the conservation and sustainable use of the ocean and its resources, one of the UN Sustainable Development Goals, is seriously underfunded. This is being rectified by the emergence of blue finance, driven by the realisation of the growing value of the ocean economy. But any investment must be targeted at sustainable economic activity and employment.

RIGHT *The Republic of Seychelles launched the world's first sovereign blue bond in 2018. Its economy is highly dependent on the ocean for food, nutrition and livelihoods, and other blue economy sectors such as tourism.*

Lucky-photographer/Shutterstock.com

Blue bonds, for example, are helping to fund not only sustainable economic development in the oceans, but also marine conservation and restoration. Asia's first blue bonds were issued through the Bank of China in 2020 for investment in environmentally beneficial projects to aid the expansion of a sustainable ocean economy. The appetite for such finance was shown a year later when the Thai Union Group PCL's Sustainability-Linked Syndicated Loan launched in Thailand and Japan was significantly oversubscribed.

In 2019, the UN Global Compact Sustainable Ocean Principles was launched. Covering ocean health and productivity, governance and engagement, data sharing and transparency, it is the world's largest corporate sustainability initiative. Subsequently, practical guidance has been issued for major ocean industries, from aquaculture and renewable energy to oil and gas, shipping and fisheries. The UN also declared 2021–30 a Decade of Ocean Science for Sustainable Development as a way of promoting investment in improving the health of the oceans.

The UN's drive for sustainable oceans is encouraging positive contributions from commercial organisations. Lloyd's Register, for example, a founding member of the UN's Action Platform for Sustainable Oceans Business, has focused its activities on meeting three sustainable development goals based around ocean transport, ocean energy and ocean food. In addition, LR has been part of the Sustainable Shipping Initiative, launched in 2010 as a collaborative global platform working towards sustainable improvements in key aspects of commercial marine activities.

Out of these initiatives has emerged the idea of the ocean citizen, adopted by many organisations around the world, such as the World Ocean Observatory. The Observatory describes Citizens of the Ocean as 'a growing network of informed individuals motivated by a love of the ocean and an understanding that global connection is a powerful way to defend and sustain the ocean.' In the UK, the charity Seaful was founded in 2020 with the express purpose of reconnecting people to the oceans, and its website encouraged the idea of active ocean citizens as advocates for the health of the oceans. In British Columbia, the Ocean Wise research organisation uses the term citizen science to encourage people to help monitor threatened species along the coast.

Enric Sala/Global Goals campaign

The *Foresight Review of Ocean Safety* draws attention to the need for new paradigms of ocean engineering and sets out the challenges and opportunities to invest in and build safe and sustainable ocean economies. It concludes that the Foundation can play a strong role supporting a safe and sustainable ocean economy by building and sharing actionable evidence and insight, convening partnerships across international and sectoral boundaries, and supporting development of new knowledge, skills and methodologies.

ABOVE *Ocean citizen, free diving world champion Umberto Pelizzari, raises a flag to represent Sustainable Development Goal 14, Life Below Water.*

Mickey Lee Mediamixer.co.uk Lloyd's Register Foundation

AFTERWORD:
COALITIONS FOR CHANGE

Many organisations from international institutions like the UN to individual charities like Lloyd's Register Foundation are working towards the resolution of the major safety challenges faced by the planet today.

LEFT *The Foundation's Safer World Conference of May 2002, brought together thought leaders from research, academia, business and government to discuss today's biggest safety challenges and new approaches needed to create a safer world.*

As the Foundation's Chief Executive, Richard Clegg, has repeatedly stressed, an effective way of tackling these pressing global safety challenges is through building coalitions for change. The Foundation itself, in the 10 years since it was established, has helped to create new networks focused on many of these problems, such as ICoN, Engineering X and the Safe Seaweed Coalition. For many of the participants in the projects supported by the Foundation, one of the lessons they have learned is the power of collaboration. This is not only collaboration across national boundaries, linking up like-minded institutions around the globe; it is also collaboration across disciplinary boundaries, often bringing together experts from different fields for the first time. In both instances, sharing knowledge has proved a powerful stimulus to innovation. It also proves the value of the initial funding given to projects by the Foundation. Clegg insisted that any project receiving Foundation support should commit to multiplying this fourfold from other sources. While the Foundation's live grant portfolio in 2022 stands at £150 million, this has generated research funding over the decade of a billion pounds.

Royal College of Art

OPPOSITE *Many of the projects supported by the Foundation illustrate the power of collaboration – such as the workshops that started the* Foresight Review *on design safety.*

The Foundation's work in pursuit of a safer world has expanded since its early days from the purely technical to embrace the wider social, economic and environmental factors affecting safety. This is reflected in the values sheet that accompanies Lloyd's Register Group's balance sheet, recording the return on the Foundation's social investment as a charity in the company. This originated from considering how shareholder value might be defined for a non-traditional shareholder like the Foundation. While financial return on investment is valued, the Foundation places equal value on social return on investment. Thinking about how social return could be articulated led to the idea of a values sheet.

This holistic approach to safety comes through strongly in the Foundation's *Foresight Review on Ocean Safety* (2021), which synthesised the views of experts from a wide range of sectors and organisations. It is also evident in many Foundation-supported projects from resilience engineering to data sharing, from SEASEP to FishSAFE 2025.

Applying fundamental research for practical impact is also an integral part of the Foundation's approach, from the output of LR's Safety Accelerator programme to the remarkable development of data-centric engineering, which is now widely taught in universities across the world. The Foundation's work recognises the advantages and disadvantages of the digital and data revolution, from the application of big data and computer analysis for


TWI Ltd

LEFT *The Foundation's support of the SEASEP programme is an example of its holistic approach to embrace the wider social, economic and environmental factors affecting safety.*


FISH Safety Foundation

enhancing safety at work to assuring the safety of robotics and autonomous systems. It appreciates that technology is our ally in tackling challenges like the energy transition at sea or the impact of extreme weather on infrastructure. Many of the Foundation's projects deliver practical and sustainable solutions for improving safety and enhancing quality of life at a local level, from fishers in Bangladesh to motorcycle delivery drivers in Taiwan.

ABOVE *Improvements in safety for the fishers in Bangladesh is one example of how the Foundation's projects can enhance the quality of life of workers throughout the world.*

As well as sharing knowledge, investing in education and training in the broadest sense is an indispensable part of any of the answers to the challenges we face: it helps to keep us safe; it opens up opportunities; it aids gender equality and greater inclusion; it allows people to make better decisions affecting the way they live. From the women welders of India to the fire engineering consultants of southern Africa, from the volunteers of the RNLI to the graduates of the International Maritime Law Institute, from the Ethiopian, Malawian and Rwandan scholars studying engineering at the University of Manchester to the young Turkish girls and boys learning from the Science Firefly, education and training help to make the world safer and fairer.

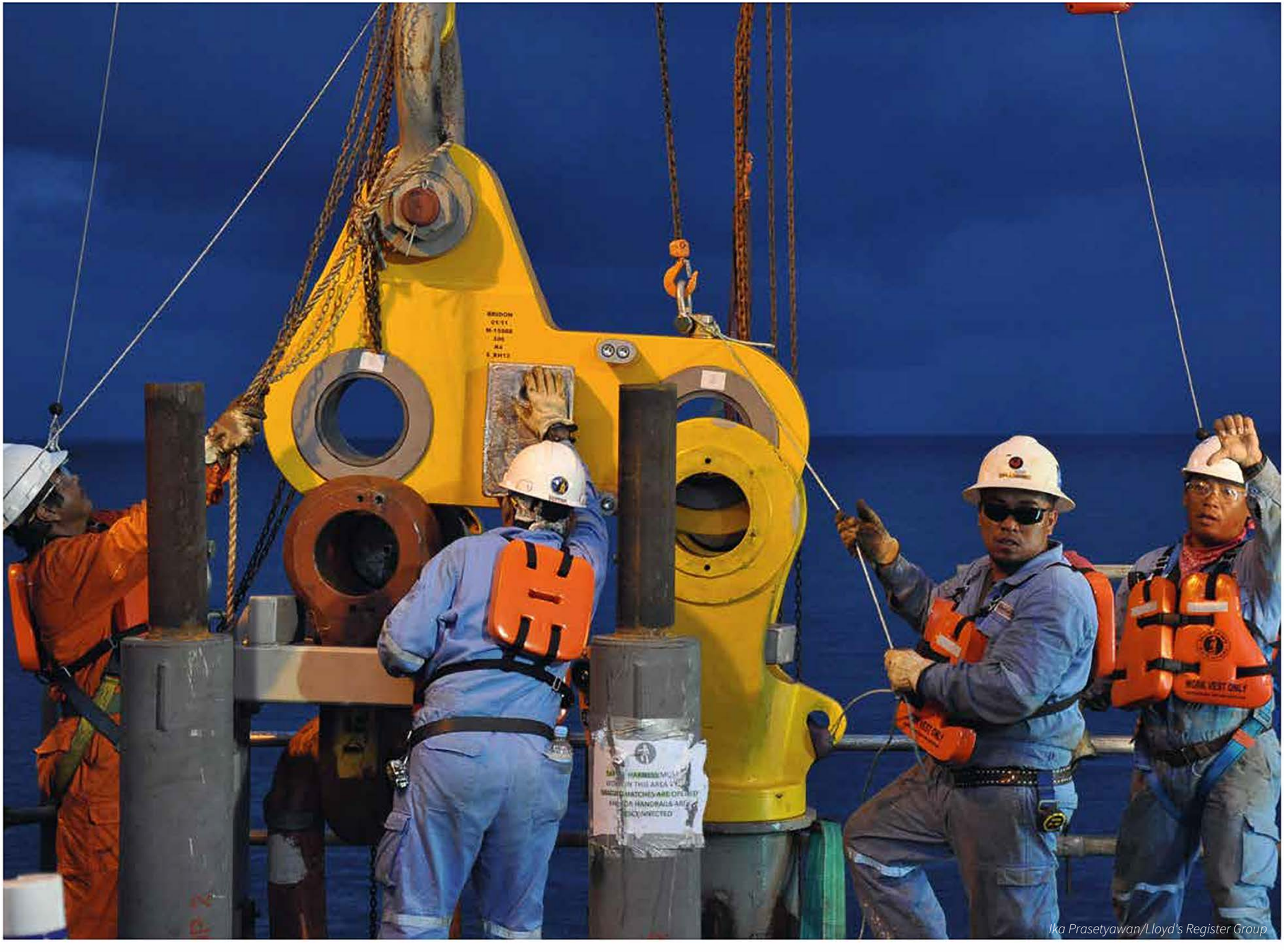
Phill Williams/1851 Trust

One of the Foundation's major achievements has been its push to develop and synthesise a comprehensive global body of evidence as the bedrock on which solutions to worldwide safety challenges can be built. Initially secured through individual projects, this is now the focus of the Foundation's Evidence and Insight Centre. The value of this approach for the Centre's Director, Dr Sarah Cumbers, came from attending the COP26 summit in 2021. 'It brought home to me why it is important to gather data globally on safety.' It highlighted how other communities had been forced to adapt to climate change because of the emissions created elsewhere. It brought home the relevance of the pioneering World Risk Poll and the importance of sharing different experiences as part of a wider world community. It also showed the value of identifying where vulnerability lies in the world and devising ways of strengthening resilience. This is also the objective of the Institute for the Public Understanding of Risk endowed jointly by the Foundation and the University of Singapore. For Clegg, this is an achievement among many he values highly. 'I love all my children equally, but I particularly love the Institute for the Public Understanding of Risk.'

The work of the Foundation – and all those many other bodies with similar aims – is far from done. The challenges remain immense. Technology continues to advance. Many people still do not take climate change seriously. The oceans remain under threat from unregulated human activity. In an increasingly complex world, as sustainability and resilience become more important, as world demographics change, as developing countries invest in significant infrastructure, safety will always be an essential part of any solution for a fairer, more sustainable planet.

OPPOSITE *The 1851 Trust's Next Generation Roadshows enabled disadvantaged young people in the UK to learn more about science and engineering.*

OVERLEAF *A global body of evidence will be the bedrock to build solutions to worldwide safety challenges, such as looking at how contextual factors are considered in safety interventions at work.*



Ika Prasetyawan/Lloyd's Register Group

TIMELINE

2012

- Lloyd's Register Foundation is set up as a new charity, with the aim to fund and support work that advances safety of life at sea, on land and in the air.
- A change in structure of Lloyd's Register is made to maximise available funding in the longer term, optimising the commercial operations of Lloyd's Register Group (LR) to further the charitable objectives of the Foundation.
- In its first year of operations, the Foundation has an income of £14.1 million, reinvesting £8.4 million in charitable activities, most involving engineering research.

Extreme weather: *Increased occurrence of natural disasters in 2012, such as Hurricane Sandy, initiated discussions of connections between aggravated risk for extreme weather events and climate change.*

Research and innovation: *After a 40-year search, a sub-atomic particle known as the Higgs Boson is discovered by the Atlas/CMS experiments at the Large Hadron Collider, Cern.*

2013

- Research Workshop in Seoul: 50 delegates from Foundation-funded centres, universities, and industry, aiming to increase co-operation.

Research and innovation: *Studies show that the security of online data is at risk, with 2,164 incidents exposing more than 823 million records globally in 2013.*

Social change: *The social media hashtag #BlackLivesMatter first appeared, and the movement and slogan gained prominence throughout the decade, cementing the growing role of social media.*

2014

- First international *Foresight Review* on nanotechnology published.
- **Grant:** The Welding Institute (TWI) and partners establish the new National Structural Integrity Research Centre in Cambridge, a postgraduate engineering facility that unites industry and academia. £15 million

Research and innovation: *The 2014 MIT Technology Review investigates the impacts of microscale 3D printing, expanding from plastic and metal alloys to semiconductors and even living cells.*

Extreme weather: *The Western United States experience exceptional drought during the first half of the year, with 64.5% of the area affected.*

Global health issues: *The UN established its first emergency health mission to provide aid to those countries hardest hit by the Ebola epidemic, which had infected 30,000 people and killed 11,000.*

2015

- Grants committed for nanotechnology research and education. £9 million

JULY

- **Grant:** UK's National Space Centre. Continuing Foundation support with new grant for lead educators and teacher CPD throughout the UK. £297,000
- **Grant:** The Alan Turing Institute. Engineering applications of big data to improve safety through advanced mathematics, computer science, algorithms, and big data. £10 million

NOVEMBER

- **Grant:** Educational Volunteers Foundation of Turkey (TEGV). Funding for a mobile science unit to bring facilities and teacher resources to remoter regions of Turkey. £132,000

Climate change: *The 2015 United Nations Climate Change Conference (COP21) led to 196 parties signing the Paris Agreement, an international treaty to combat climate change, effective from 4 November 2016.*

DECEMBER

- **Grant:** RNLI. Training for volunteer lifeboat crews in sea survival skills. £1.1 million

Feeding the world: *In 2015, the UN published a report stating that 829 million people globally are undernourished.*

2016

MAY

- **Grant:** Enhancing Safety through Law. Scholarship funding for three candidates per year from developing states at the International Maritime Law Institute, to gain unique legal expertise making them a valuable resource to policy and decision-makers in their governments.
- **Grant:** Lloyd's Register Foundation Institute for the Public Understanding of Risk at the National University of Singapore. The first of its kind in Asia, undertaking research, education and building connections with practical end users. £10 million

JUNE

Grant: Project for the Safe Production of Marine Plants and Use of Ocean Space. Wageningen University & Research. Support for the safe production of marine plants and use of ocean space (SOMOS) project. £500,000

Grant: Resilience Shift. The programme, in partnership with Arup, aims to make infrastructure more resilient in critical sectors including energy, transport, food and water. £10 million

Research and innovation: *A third set of Panama Canal locks opened to commercial traffic on 26 June 2016, doubling the capacity of the Canal and allowing for larger ships known as New Panamax, to pass through.*

OCTOBER

Grant: Global safety challenges. Nesta's Challenge Prize Centre identifies, prioritises, and recommends solutions to address the greatest risks to safety related to the critical infrastructure on which society relies. £90,000

DECEMBER

Grant: Internet of Things (IoT) resilience. PETRAS, the UK research hub for cybersecurity of the Internet of Things, has initiated a broad spectrum of projects. £250,000

Research and innovation: *Klaus Schwab (World Economic Forum) coins the concept of Industry 4.0, characterised by the convergence of advanced technologies, including robotics and automation, nanotechnology, and advanced digital production.*

2017

FEBRUARY

Grant: A smarter bridge. MX3D lead a consortium to build the world's first 3-D printed steel bridge. £247,000

OCTOBER

Grant: Assuring Autonomy International Programme. Focusing on areas such as AI in driverless vehicles and robots in healthcare and developing a process that will be the first documented approach to assuring the safety of machine learning components. £10 million

Disinformation: *'Oumuamua (the Hawaiian term for scout) is the first interstellar object detected passing through our solar system – not an alien spacecraft as suggested on social media.*

DECEMBER

LR Safety Accelerator launched. A global programme to accelerate safety innovation in industry.

Social change: *A report from the Oxford Poverty & Human Development Initiative maps the distribution of people affected by poverty, identifying South and Southeast Asia as the regions with most poor in absolute terms with 48% of the global poor.*

2018

JANUARY

Grant: HiLo. The Foundation funds the expansion of the HiLo system across the shipping industry, helping to avoid predictable accidents in the future.

MAY

The Foundation and HSE announce the 'Discovering Safety' data-driven programme, to improve health and safety and save lives, particularly in poorer or developing nations.

JUNE

Grant: Fire Engineering Education for Africa, Stellenbosch University. First ever postgraduate (MEng and PhD) courses in fire engineering in Africa. £165,000

SEPTEMBER

Grant: World Risk Poll. Exploring how people worldwide understand risk, and how their perceptions affect their decision-making process. Poll to be taken four times over eight years. £14 million

OCTOBER

Grant: SEASEP. The Southeast Asia Skills Enhancement Programme. Programme led by TWI to improve safety associated with the construction of new critical infrastructures across a range of industries. £2 million

Grant: End of engineered life. Engineering X's programme to improve safety in waste and decommissioning of assets for industrial and engineered systems. £5 million

Conserving the oceans: *Figures from the UN Food and Agriculture Organisation show that over 27 million tonnes of marine life are discarded annually due to overfishing.*

Climate change: *Between 2016 and 2018, an average of 28 million hectares of forest disappeared.*

International incidents: *On 25 November 2018, the Kerch Strait incident triggers martial law in Ukraine.*

2019

JULY

Grant: Ohalo. Three-month data X-ray pilot to automatically anonymise and desensitise data within 600,000 records from the UK's HSE. £30,000

Disinformation: *The UK Parliament publishes a report on the impact and causes of disinformation and 'fake news' calling tech companies to action.*

Extreme weather: *A series of unusual wildfires sweeping through the UK between February and May affect more than 29,000 hectares of land, elevated temperatures being a contributory factor.*

Research and innovation: *An international team at the Event Horizon Telescope take the first ever image of a black hole.*

2020

JANUARY

Grant: Toolbox: A web app that provides health and safety insights from leading energy companies reminding workers of how to work safely. £200,000

MARCH

Grant: Pioneering the next wave of aviation innovation. Vianair Inc software enables airport authorities to efficiently plan, design and manage airspace and airport systems, and make balanced, considered decisions resulting in safer operations. £200,000

JULY

fishSAFE 2025. The fishSAFE 2025 project launches a train-the-trainer programme for around 15 people to kick off a process that will grow organically and ultimately train 400 fishers, trawler owners and skippers.

Global health issues: *The COVID-19 pandemic hits the world, forcing countries to put in place unprecedented measures to ensure safety. By April 2022, confirmed cases had exceeded 500 million and the global death toll surpasses 6 million people.*

Disinformation: *The rise in Covid-19 infections triggers a wave of disinformation on social media platform, linking alleged dangers of the new 5G internet technology.*

Social change: *The murder of George Floyd on 25 May 2020 sparks protests across the United States and around the world.*

2021

Grant: Next Generation Sailing Roadshows. The 1851 Trust encourages a new awareness of maritime safety, helping the next generation access the valuable history of Lloyd's Register. £141,000

AUGUST

Grant: FerrySafe. Project to investigate transforming safety performance in the ferry industry in low and middle-income countries, aiming to generate a set of regulations to increase safety.

Millionth document captured. The number of historic plans and survey reports, captured and digitised for the HEC website, passes 1 million.

Climate Change: *The COP26 conference highlighted devastating future scenarios connected to climate change if actions toward reducing greenhouse gas emissions are not taken.*

Climate change: *A* National Geographic *report finds annual sea-levels are rising by about 3.2mm and accelerating. With an expected rise of 300mm by 2050, the levels would have risen more in the next 30 years than they have in the past century.*

International incidents: *The container ship* Ever Given *obstructs the Suez Canal for six days, causing prolonged delays and backlogs in the movement of seaborne goods, costing an estimated $3.6 billion in global trade.*

2022

JANUARY

Grant: Resilience Rising. Resilience Rising is a global non-profit consortium innovating to make systemic resilience the norm as society transforms towards a net-zero future, ensuring that the world's infrastructure can quickly recover from acute shocks and chronic stresses and adapt to a continually changing world. £3.75 million

Social change: *The UN economic analysis suggests higher fuel prices are causing high inflation globally, while the COVID-19 pandemic and geopolitical conflicts are contributing to food insecurity. Some 283 million people in 80 countries are estimated as acutely food insecure or at high risk.*

LIST OF ABBREVIATIONS

AAIP Assuring Autonomy International Programme

AI Artificial Intelligence

ATI Alan Turing Institute

CAMFED Campaign for Female Education

CEPOLAR Centre of Excellence for Scenario-based Risk Management in Polar Waters

CHIRP Confidential Hazardous Incident Reporting Scheme

CITiZAN Coastal and Intertidal Zone Archaeological Network

COP26 2021 United Nations Climate Change Conference

CSIC Cambridge Centre for Smart Infrastructure and Construction

FAA Federal Aviation Authority

FAO Food and Agriculture Organization

FSF FISH Safety Foundation

GHG Greenhouse gas emissions

HEC Heritage and Education Centre

HSE Health and Safety Executive

ICASS International Centre for Advanced Safety Studies

ICoN International Consortium of Nanotechnologies

ILO International Labour Organization

IMLI International Maritime Law Institute

IMO International Maritime Organization

IoT Internet of Things

IPUR Institute for the Public Understanding of Risk

IWSN International Water Security Network

LNG Liquefied natural gas

LR Lloyd's Register Group

LRET Lloyd's Register Educational Trust

MIT Massachusetts Institute of Technology

NGO non-government organization

NSA National Space Academy

NSIRC National Structural Integrity Research Centre

ODI Open Data Institute

OECD Organisation for Economic Co-operation and Development

ORCA Offshore Robotics for the Certification of Assets

PETRAS Privacy, Ethics, Trust, Reliability, Acceptability and Security

RNLI Royal National Lifeboat Institution

SEASEP Southeast Asia Skills Enhancement Programme

STEM science, technology, engineering and mathematics

TEGV Educational Volunteers Foundation of Turkey

TWI The Welding Institute

UCL University College, London

WHO World Health Organization

SOURCES

The following sources were used in compiling this book.

LIST OF DOCUMENTS CONSULTED

Lloyd's Register Foundation Annual Reports/Annual Reviews

Lloyd's Register Foundation *Foresight Reviews*

- Big Data
- Cyber Security for the Industrial IoT
- Design for Safety
- Energy Storage
- Food Safety
- Future of Regulatory Systems
- Global Safety Evidence
- Ocean Safety
- Public Understanding of Risk
- Resilience Engineering
- Robotics and Autonomous Systems
- Structural Integrity and Systems Performance

Lloyd's Register Foundation *Insight Reports*

- Distributed Ledger Technologies
- Global Safety Challenges
- Safety in the Fishing Industry
- Safety in the Passenger Ferry Industry
- Sharing Engineering Data

LR Annual Reports/Group Reviews

Miscellaneous Foundation Material

- 3D Printed Bridge
- Data-centric Engineering
- Decarbonisation Hub
- Evidence and Insight Centre
- Fishing Industry
- Governance and Strategy
- Grants and Project Proposals
- Lloyd's Register Foundation Chief Executive's Reports
- Nanotechnology
- Oceans

LIST OF WEBSITES CONSULTED

http://extrememarine.ocean.dal.ca
http://graphics.eiu.com/upload/eb/DiversityandInclusion.pdf
http://kula.geol.wwu.edu/rjmitch/coastalpopulation.pdf
https://allianceforscience.cornell.edu
https://autonomy-and-verification-uol.github.io/files/presentations/AAIP-Programme-Overview-20180906.pdf
https://camfed.org
https://climate-adapt.eea.europa.eu
https://daily.jstor.org
https://discovery.ucl.ac.uk/id/eprint/10083097/3/Lu_A%20Digital%20Twin%20of%20Bridges%20for%20Structural%20Health%20Monitoring_AAM.pdf
https://ec.europa.eu
https://ec.europa.eu/jrc/sites/default/files/jrc-resilience-in-a-globalised-world_en.pdf
https://edition.cnn.com
https://ejfoundation.org
https://en.unesco.org
https://english.deltaprogramma.nl
https://geology.wwu.edu
https://hec.lrfoundation.org.uk
https://i.unu.edu/media/ehs.unu.edu/attachment/23907/UN_Interconnected_Disaster_Risks_Report_210902_Full_Report.pdf
https://industrytoday.com
https://infrastructure-complexity.springeropen.com
https://investors-corner.bnpparibas-am.com
https://leftronic.com
https://londoninternationalshippingweek.com
https://maraseaweed.com
https://nationalspaceacademy.org
https://news.mongabay.com
https://news.un.org
https://ourworldindata.org
https://podfollow.com
https://pubs.acs.org
https://sdgs.un.org
https://seaful.org.uk
https://spacecareers.uk
https://sustainabledevelopment.un.org
https://theconversation.com
https://thefishsite.com
https://time.com
https://unfoundation.org
https://ungc-communications-assets.s3.amazonaws.com/docs/publications/The-Seaweed-Manifesto.pdf
https://unglobalcompact.org
https://wearebloc.io
https://webfoundation.org
https://world-nuclear.org
https://worldhappiness.report
wrp.lrfoundation.org.uk
www-smartinfrastructure.eng.cam.ac.uk
www.adsadvance.co.uk
www.bbc.co.uk
www.bbc.com
www.bcg.com
www.broadbandcommission.org/Documents/working-groups/FoE_Disinfo_Report.pdf
www.bworldonline.com
www.cambridge.org
www.carbontrust.com
www.cdbb.cam.ac.uk
www.cdc.gov
www.city.ac.uk
www.cnbc.com
www.cozev.org
www.csc.gov.sg
www.discoveringsafety.com
www.economist.com
www.europarl.europa.eu/RegData/etudes/STUD/2021/653635/EXPO_STU(2021)653635_EN.pdf
www.fao.org
www.fao.org/3/cb2863en/cb2863en.pdf
www.fishsafety.org
www.food.gov.uk
www.foodsecurity.ac.uk

www.frontiersin.org
www.ft.com
www.gihub.org
www.globalminingreview.com
www.globalslaveryindex.org
www.greenmatters.com
www.ibm.com
www.ilo.org/wcmsp5/groups/public/---asia/
---ro-bangkok/documents/publication/wcms_426563.pdf
www.imf.org
www.iucn.org
www.lr.org
www.lrfoundation.org.uk
www.mckinsey.com
www.mckinsey.com/~/media/mckinsey/industries/agriculture/our%20
insights/reducing%20agriculture%20emissions%20through%20
improved%20farming%20practices/agriculture-and-climate-change.pdf
www.mja.com.au
www.mpa.gov.sg
www.ncbi.nlm.nih.gov
www.newcivilengineer.com
www.nrfis.cam.ac.uk
www.oecd.org/derec/50313960.pdf
www.open.edu
www.permaculturenews.org
www.poseidonprinciples.org
www.pwc.co.uk
www.raeng.org.uk
www.rca.ac.uk
www.resilience-engineering-association.org/download/resources/
symposium/symposium_2015/Yoshizawa_A.-et-al-Experiences-in-
Fukushima-Dai-ichi-Nuclear-Power-Plant-in-light-of-resilience-
engineering-Paper.pdf
www.resilienceshift.org
www.rshq.qld.gov.au
www.safeseaweedcoalition.org
www.sciencedaily.com
www.sciencedirect.com
www.seanews.co.uk
www.seatrade-maritime.com
www.seattle.gov/documents/Departments/Emergency/PlansOEM/
SHIVA/2014-04-23_InfrastructureFailures.pdf
www.ship-technology.com
www.slingshotsimulations.com
www.solent.ac.uk
www.southampton.ac.uk
www.statista.com
www.sustainableshipping.org
www.tandfonline.com
www.theengineer.co.uk
www.theguardian.com
www.theweek.co.uk
www.theweldinginstitute.com
www.transportenvironment.org
www.turing.ac.uk
www.twi-global.com
www.twitraining.com
www.ucl.ac.uk
www.ukri.org
www.un.org
www.understandrisk.org
www.unglobalcompact.org
www.unwater.org
www.watersecuritynetwork.org
www.weforum.org
www.wildlabs.net
www.worldbank.org
www.worldwildlife.org
www.york.ac.uk

For a full list of web pages and sources consulted go to:
https://www.lrfoundation.org.uk/en/a-safer-world-sources/

LIST OF INTERVIEWEES

Positions listed refer to roles held by individuals at the time interviews were conducted.

Attard, David, Director, IMO International Maritime Law Institute
Boumphrey, Ruth, Director of Research, Lloyd's Register Foundation
Brown, Nick, Chief Executive, Lloyd's Register Group
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Chander, Manit, Managing Director, HiLo
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Girolami, Mark, Chief Scientist, Alan Turing Institute
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Holliday, Eric, Chief Executive, FishSAFE Foundation
Jenkins, Vince, former Global Head of Technology, Lloyd's Register Group
Kent, Tim, Technical Director, Lloyd's Register Group
Khalid, Aamir, Chief Executive, The Welding Institute
Koh, C. G., Director, Institute for the Public Understanding of Risk, Singapore
Laing, Sir Kirby, Professor of Civil Engineering at the University of Cambridge
Majumdar, Arnab, Professor of Transport Risk and Safety, Imperial College, London
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Przydatek, Jan, Director of Technologies, Lloyd's Register Foundation
Reeve, Simon, Director of Commercial Engagement, Lloyd's Register Foundation
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Sillem, Hayaatun, Chief Executive, Royal Academy of Engineering
Slingsby, Tim, Director of Skills and Education, Lloyd's Register Foundation
Sohmen-Pao, Andreas, Trustee, Lloyd's Register Foundation
Stitt, Alex, Director, Heritage and Education Centre, Lloyd's Register Foundation
Thune Andersen, Thomas, Trustee and Chair, Lloyd's Register Foundation and Lloyd's Register Group
Van der Velden, Gijs, Chief Executive, MX3D
Varnavides, Lambros, Trustee, Lloyd's Register Foundation
Walls, Richard, Professor of Structural and Fire Engineering, Stellenbosch University
Wilford, John, Group Strategy Director, Lloyd's Register Group

Informal interviews were also conducted with other members of Lloyd's Register Group and Lloyd's Register Foundation – **Daryl Attwood**, **Haibo Chen**, **Sean Clemenson**, **Beth Elliot**, **Charles Haskell**, **Oyegbe Ibhanesebhor**, **Suzanne Johnson**, **Barbara Jones**, **David Reid**, **Olivia Swift** and **Chris White**.

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Nigel Watson

Engineering a safer world is no mean feat. I hope that as you gallop through projects that we have supported over the last 10 years, framed by the safety challenges facing the world, this book will reveal, or in some cases, reaffirm just how important our work is. Especial thanks to Richard Clegg for his idea to produce this book, and for his many 'crystal ball' moments over the years. As lead editor, I also want to give particular thanks to Sarah Mott for organising the interviews, to Barbara Jones and Jan Przydatek for their detailed feedback, Luca Rapisarda for image and timeline research, Jane Ace for helping to get things going, to all of our reviewers and, of course, the tireless work of my co-editors Kathy Davis and Katie Hewett. We also want to ensure that we recognise and highlight the work of our grant holders, and of the many, many others, who help the Foundation to achieve its mission. Details of all our grants can be found at www.lrfoundation.org.uk/en/400-manage/our-grants-data

Louise Sanger

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