Lloyd's Register Foundation

Foresight review of the future of regulatory systems

Regulating in a disruptive world

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About Lloyd's Register Foundation

Our vision

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

Lloyd's Register Foundation charitable mission

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

About the Lloyd's Register Foundation Report Series

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

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Executive summary

The health, wellbeing and security of people, and a strong economy, depend on our social, physical and natural infrastructures. Societies can quickly crumble when these are disrupted. Regulation has shown its value over many years as one of the tools used by governments to manage risks to critical infrastructures and to protect people from harm.

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Yet many regulatory methods were designed for worlds and risks that can be very different from those faced today. Innovations using technology can now move seamlessly across sector or national boundaries at speeds and scales not previously experienced. Inter-dependencies between physical, natural and societal systems mean that a local failure in one system can rapidly cascade to the others, potentially crossing "tipping points" after which any significant changes cannot be easily reversed. Also society is changing. People's views about the world around them, informed in part by powerful social media, have become more polarised. This adds to increasingly complex relationships between society, science and technology.

What are the potential implications for regulation of disruptive trends like these?

First, it places greater emphasis on the "regulatory system". Taking a whole-of-system perspective opens up more options for achieving regulatory outcomes than simply defining and enforcing "rules". For example, it creates opportunities for the many people and organisations across the regulatory system to become more involved in shaping and delivering the intended outcomes. Thinking in terms of the system can also improve understanding of local contexts (what works well in one geography or industry sector may not be effective or appropriate in another) and of those developments beyond the system boundaries that might affect it.

Second, innovations seen elsewhere in business and society can be applied within regulatory systems. These can create regulatory models that are more forward looking, experimental and collaborative. For example, decision sciences are helping us

understand better why people take decisions that may lead to harm, with this insight used to design and test suitable responses. Technology and data sharing is enabling earlier sight of emerging issues and more efficient ways of monitoring regulatory compliance.

Third, disruptive trends can apply pressure to existing (or new) vulnerabilities. Regulatory systems can be undermined by the influence of politics or powerful industry players, or by knowledge imbalances when industry expertise is far ahead of the regulator's expertise. They can struggle with long term issues or those attracting divergent societal views. Some existing practices may not work for fast moving and highly interconnected systems, or for risks that cross regulatory, industry or national boundaries. Regulatory vulnerabilities such as these can be intensified and exposed by the complexity, chaos and contradictions of disruptive worlds.

In addition, regulatory decisions may have to be taken at pace while simultaneously grappling with deep uncertainties about the issues in question, imperfect information and the need to balance multi-dimensional trade-offs (such as safety, social, environmental and economic aspects). And the stakes are high – inappropriate responses can lead to infrastructure failures that threaten lives and livelihoods.

In practice, most issues will not have such high levels of complexity and vulnerabilities will be managed. Well designed regulatory systems will continue to work well, but it will be crucial to recognise their limits.

There is no simple answer to regulating in a disrupotive world. Sustaining public trust is crucial, particularly if the pace of change and uncertainties place a focus on coping and adaptation (as opposed to the more usual expectations of control and certainty). Desirable attributes for regulatory systems would include:

- **Systems thinking** – with regulatory designs that take account of the inter-connections between the many organisations and people in the regulatory system, and of the external factors that disrupt (or become disrupted by) how the overall system behaves. It also requires mechanisms to deal with issues lying entirely outside existing regulatory boundaries, where there may be no obvious lead regulator.
- **Diversity** – with regulatory responses that draw on collaboration, diverse thinking and a range of regulatory tools that are combined and tailored to the conditions being faced. This will need deep understanding of the strengths and limitations of any given regulatory approach, which includes overcoming those unconscious biases that may lead to perceptive voices not being heard.
- **Adaptive leadership** – with an explicit acknowledgement of uncertainty, anticipation of how issues might develop, and the ability to flex regulatory responses in the light of rapidly changing demands or new information. This style of leadership places even more importance on the trustworthiness of key players within the regulatory system.

Implementation of such attributes is easier in theory than practice. There are big questions to resolve, for example: Under what conditions will an increasingly fragmented society accept experimentation and adaptation? How do you ensure fair regulatory systems, when these may depend on who is at the table creating them and whose voices are heard? How do you differentiate between straightforward issues where established methods work well and those disruptive ones that create radically different demands, when the differences are not always self-evident? Who regulates the regulators, and resolves the trade-offs between precaution, innovation and resilience?

The diverse inputs to this review created a sense that many answers already exist – but also that ideas are not being connected and lessons from past regulatory experience are not being learnt.

Strengthening mechanisms for improving the sharing of knowledge across national and industry borders could add considerable value. Given the range and diversity of inputs involved, a focal point is required to provide the necessary focus and leadership that brings together the many siloes that already exist. An independent, inclusive and strongly applied "critical knowledge hub" could achieve this, with early actions creating: a knowledge repository that provides a practical and accessible synthesis of available information in the

public domain, with value added through elements such as creating an "early warning network" for emerging issues; deliberative mechanisms that allow a diverse, dispersed community to share insights, debate ideas and build collective understanding; a compendium of regulatory tools that draws out their potential applications and limitations, with insights about future issues that these tools may need to contend with.

Lloyd's Register Foundation is well positioned to bring together thought leaders, decision makers and practitioners to share knowledge, and to use its existing investments to show what could be done. It could drive action to shape the detail and build momentum for the next steps. Better stewardship and mainstreaming of currently fragmented knowledge can accelerate adoption of new and more effective regulatory methods and raise awareness of emerging threats. It could contribute to protecting the lives and livelihoods of people around the globe for the disruptive decades to come. It is an immense opportunity.

Foreword

Governments around the world use regulation to protect people from harm and to maintain the social, physical and natural infrastructures that our societies rely on. Regulation influences many aspects of our lives – such as the food and clean water that we need to keep healthy; the energy that powers our homes and industries; the communication and transport networks that connect our communities; and the natural environment that is so important to our planet's future.

Increasingly sophisticated regulatory systems are being used to good effect in many parts of the world and have delivered massive benefits for society over many decades. Yet, alongside the successes, we still see more than 2 million work related deaths each year from accidents and long-term diseases, and catastrophic disasters such as the Boeing 737 Max crashes, the failure of the Brumadinho tailings dam in Brazil and the Beirut Port explosion. These are powerful reminders that even more can be done.

Our regulatory systems are also facing new threats, opportunities and questions. Regulatory boundaries and the effectiveness of established regulatory tools are being challenged by innovations in technology and business models, by the pace of change and scale of connectivity that these often involve, and by people's changing views about their societies and the world around them. Examples such as cyber threats, artificial intelligence, climate change and extreme societal injustices present new types of challenge.

This report takes the reader on a journey to understand how regulatory systems work and their vulnerabilities, the disruptions that will challenge how we regulate at present, and the opportunities that these same disruptions offer to how we approach regulating in the future. What comes across from this review is that there is plenty of scope for innovation that evolves and improves how we regulate familiar issues.

It is equally clear that previously successful regulatory practices may not work when faced with the demands of disruptive worlds. It is timely to raise awareness of the issues, to draw together relevant international experience and to identify those approaches that could help regulatory systems cope better under these challenging conditions. In doing so, this review contributes to protecting lives and livelihoods for the disruptive decades to come.

Professor Richard Clegg
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Photo by Jacek Dylag on Unsplash

Background

This review seeks to make sense of how disruptive developments...might impact regulatory systems

This review seeks to make sense of how disruptive developments, with their high levels of complexity and uncertainty, might impact regulatory systems. Its emphasis is on social regulation (that aims, for example, to reduce risk of harms to the health, safety or wellbeing of people, or to the built and natural environments) as opposed to market or financial regulation. It sets out to disseminate information, provide an overview of established and emerging methods, frame key questions, identify options and recommend actions that will help prepare for the futures that may unfold. It should be seen as a first step in raising awareness and prompting debate about disruptive futures.

It explores the impacts of disruptive technologies and business models that may affect critical infrastructures over the next 10 to15 years. By critical infrastructure we mean those systems that protect communities; provide essential services such as energy and water; connect communities via transport and communications networks to enable the flow of goods and information. This definition extends beyond physical assets to include the data, knowledge and the institutional infrastructures that underpin regulations.

The review focuses primarily on established regulatory regimes, generally those in Western democracies. Although this does create some bias, it provides a good starting point and many of the observations have wider global applicability. Political and societal attitudes vary extensively around the world, and these different international contexts influence regulatory designs and behaviour. There is scope to build upon this review to explore implications for other models of government or for those nations lacking established regulatory systems (which may offer even more opportunity for regulatory innovation, for example through using technology to improve on practices in developed economies that may be more constrained by deeply embedded systems and processes).

The review drew on a wide range of organisational, disciplinary and geographical perspectives, with that diversity of views being central to the approach taken. The findings and recommendations are built on a series of around 50 interviews, four workshops and peer reviews, from which key themes and issues were synthesised, debated and considered for inclusion. The many individuals whose inputs helped shape this review are listed alphabetically in Appendix A.

Workshops and discussions were hosted by Lloyd's Register Foundation, London, UK; Better Regulation Executive, London, UK; Carnegie Mellon University, Pittsburgh, US; Duke University, Durham, US; EPFL International Risk Governance Centre, Lausanne, Switzerland and Civil Service College, Singapore. The authors are grateful to these organisations for their support.

The review is indebted to the many people who so generously gave their time and insights. The authors thank the advisory board and everyone involved for their energy and thoughtful contributions to the production of the review.

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Advisory board

Regulatory context

The health, wellbeing and security of people, and a strong economy, are all dependent on our social, physical and natural infrastructures. Societies can crumble very quickly when these infrastructures are disrupted. By helping to ensure their resilience, regulation plays an important role in maintaining social structure and cohesion.

Regulation is not new. The Babylonian Code of Hammurabi, almost 4,000 years old, contained several laws relating to the built environment. The concept of rules backed up with penalties was strengthened at the dawn of the industrial age, some 200 years ago, when specialist regulatory inspectors were introduced to enforce rules that protected people.

The numbers of regulations and regulatory bodies have grown across the globe over the last 200 years. This growth has been accelerated by technological and economic change to the point where – in many developed economies – nearly every part of their economy is subject to some form of regulation (see figure 1 overleaf). This growth has also led to calls for better regulation, responding to concerns about regulatory costs, proportionality and negative impacts on innovation and competition.

Why regulate?

The rationale for regulation is that businesses and individuals, left to their own devices, may behave in ways inconsistent with the public interest or government policies. Regulation shapes the "right" behaviours.

Regulations are generally associated with controls to manage the risk of harm to consumers, workers, the environment or society more generally; to promote economic efficiency; or to ensure common standards that create a level playing field for competing businesses and enable economies of scale.

> "In the end, regulatory outcomes have to be something the public accept as fair. If you don't have that, whatever nice theories you have, the system collapses. A big question should always be 'how does the public view this'."
>
> **Dan Corry**, Chief Executive, New Philanthropy Capital (former Senior Adviser to the UK Prime Minister, 2007-10)

Good regulation can also enable or encourage innovation – for example vehicle emissions standards set by EU and US regulators sparked the development and implementation of the automotive catalytic converter.

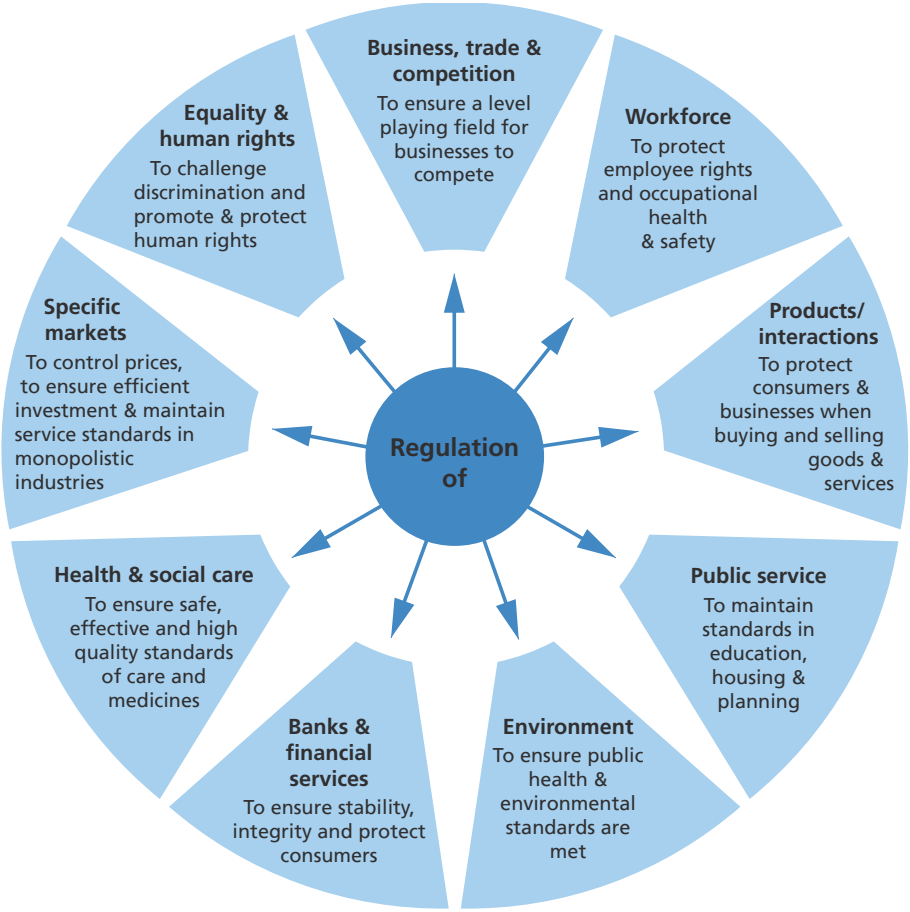

Figure 1: Examples of regulatory purpose (based on UK National Audit Office guide to regulation[1])

Conversely, the absence of effective regulation can lead to human, industrial, ecological and economic disasters. Examples include the social impacts of online harms and fake news, which can be life threatening and politically destabilising; and deforestation whose consequences include displacing wildlife closer to human communities leading to viral outbreaks or altering the ability to store rainfall resulting in flooding of cities and other critical infrastructure. The stakes can be high.

What triggers regulatory changes?

Regulations are not static, they evolve with time. This evolution is influenced by changing political contexts, and often triggered by reactions to major incidents and visible threats, to innovations or to societal pressures. For example, regulations have changed:

- to respond to major tragedies: sinking of the "unsinkable" RMS Titanic after hitting an iceberg on her maiden voyage led to international cooperation on safety regulations and the 1914 International Convention for the Safety of Life at Sea (SOLAS); the Pike River mining disaster in 2010 led to step changes in New Zealand's regulatory frameworks
- to deal with new applications of technology: the EU directives surrounding use of genetically engineered foods (GMOs) or data protection; revision of the 1968 Vienna Convention on Road Traffic (to which 72 countries are party) to take such new technologies such as self driving vehicles into consideration
- to tackle extreme inequality, real and perceived injustice, or social unrest: the UK's Equalities Act 2010 shaped by 14 years of public campaigning, and many reforms in US state laws responding to the #MeToo movement.

This reactive approach creates specific challenges for managing risks that only become apparent at some time in the future (latent issues), such as the health impacts of asbestos. It can also drive a cyclical pattern in which a disaster or visible threat triggers major change, followed by a period when success in controlling harm leads to deregulation as the reasons for the controls are forgotten – until the next disaster.

Ultimately, regulations can become redundant, but their removal is rarely straightforward.

Regulatory systems

Regulation is often thought of in terms of the laws that are applied and enforced by the state to achieve desired business and individual behaviours.

But achieving these desired behaviours is not simply about the law and its enforcement by a regulator. There are many other organisations and people that, together with the rules, can work together to influence behaviours and achieve the intended regulatory outcomes (see figure 2).

Thinking in terms of a "regulatory system" allows a broader perspective of the various influences that can shape regulatory outcomes and in turn gives access to a wider range of regulatory options to shape the intended behaviours.

This section outlines the attributes of a regulatory system, considers what is needed for good regulatory design and identifies vulnerabilities that – if not managed – can result in regulatory failure.

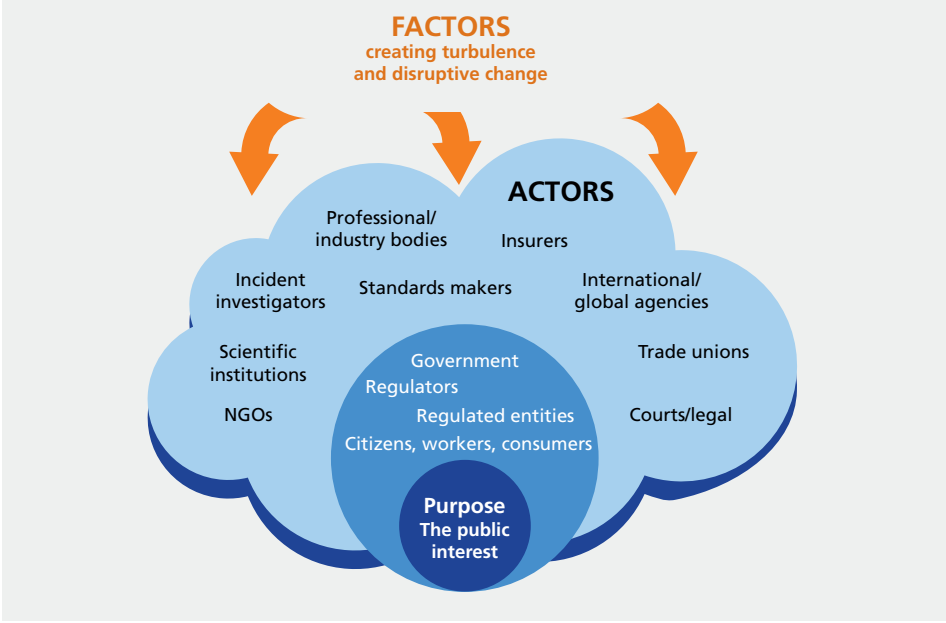

Figure 2: A generic regulatory system (adapted from Emery, Trist et al[2])

Attributes of a regulatory system

A regulatory system can be described in terms of its purpose and properties, the relationships between the key organisations and people involved (the actors), its boundaries, and its interactions with external environments beyond its boundaries – including other regulatory systems. Each of these can change over time, with a system's history influencing how it looks today. The past does not, however, predict the future – particularly in rapidly changing worlds.

Purpose and essential properties

Having a clear definition of system purpose (or regulatory intent) is fundamental. Regulatory purpose is often captured in law and, as shown in figure 1, linked to specific issues (such as food safety or protecting personal data) or industry groupings (such as construction or utilities).

Regulatory purpose can change quite significantly over time. For example, UK utility regulators originally set up to monitor a newly privatised market now have increased focus on protecting consumers from the impacts of climate change. A good question is always "what are we trying to regulate and why".

Not everything changes when regulatory purpose changes. The system will have essential properties that remain constant, such as inclusivity, dependability, or resilience. Although these properties are rarely stated or defined, doing so can help when assessing the impacts of innovations or regulatory developments.

Actors

The regulatory system is made up of many people and organisations (figure 2) whose inter-dependent actions influence how others, and the overall system, behave. These are known as "actors" and are increasingly connected through data, technology and social media. The actors do not have to be human: as artificial intelligence (AI) gets more deeply embedded, it may itself need to be considered as a system actor.

Government and regulators play a crucial leadership role by setting the tone and promoting action within the regulatory system. They can drive positive change through both hard powers (such as incentives, enforcement, sanctions) and soft powers (such as setting the agenda, communications, building coalitions).

Regulated organisations and the beneficiaries of regulation (such as workforces, consumers and communities) sit alongside government and regulators at the centre of regulatory systems. Engaging with these groups, or their representatives such as trade unions, consumer or industry bodies, provides valuable insights into attitudes towards regulation and compliance. It can also enable concerns or ideas for improvements to be voiced and can encourage shared ownership of issues.

There are many others who can be involved in the regulatory system. Non-government organisations (NGOs) can drive reform at a global level. There are also those with remits that underpin regulation: independent classification societies such as Lloyd's Register establish and monitor standards on marine vessels to provide certifications confirming compliance with International Maritime Organization agreements.

Boundaries

The system boundary is of critical importance. It is directly linked to the purpose and defines what is, or is not, covered by the regulations and the remits of the regulators involved.

The boundary is often captured by tight legal definitions, but these can lead to future problems. Systems designed for past industrial groupings or business models can find it difficult to adapt to more recent developments such as the online platforms that cut across established regulatory remits or industry sectors.

The system purpose, and hence its boundaries, can function at different levels. They can be tightly focused on a specific issue, such as environmental protection, or could bring together multiple regulators to operate as a system of systems: for example, regulatory oversight of major petrochemical facilities takes account of public safety, environmental and security

impacts. It can also span geographic boundaries at national, regional or global levels: harms such as spread of disease, economic impacts, or environmental issues (such as those linked to climate change) cannot be readily contained within geographic borders.

Systems crossing boundaries (whether geographic, industry sector or regulatory) need clarity on who is tasked with the system-wide overview. They also need mechanisms to resolve trade-offs (such as between cyber and safety, or efficiency and resilience) and to secure key data flows between their component parts.

Contextual environment

A regulatory system does not operate in isolation but has a two-way interaction with the world beyond its boundaries – its contextual environment. Developments outside the regulatory system can create instability and turbulence within the system, for example as political attitudes or societal expectations change.

Conversely, actions taken within the regulatory system can have consequences for those outside the system. This can be positive, such as the improved productivity often seen in safer workplaces. Or there can be negative consequences that are unintended and not immediately visible. For example, security controls at airports and changed passenger behaviours after the 9/11 terrorist attacks in the United States led to a switch from air to road use. That resulted in an estimated 1,595 additional deaths nationwide the following year due to road traffic accidents.

Regulatory design

When successfully designed and implemented, regulatory systems deliver important benefits to society and to businesses. When poorly designed, they can contribute to accidents, impose unnecessary costs, stifle innovation, lead to corruption and fail to meet public expectations. In some cases, a relevant regulatory system may simply not exist.

There are generic questions to ask of a regulatory design that will be relevant in any context. These include:

- What is the regulatory system, its purpose and its essential properties?
- Does it drive the right behaviours? Are accountabilities clear?
- Can it adapt? What is its sensitivity to changes in system boundaries, uncertainties or external events?
- How does it account for interactions between technology and people (the "socio-technical" aspects)?
- How does it manage critical data flows – within the system and, potentially, across its boundaries?

Taking a systems perspective, as opposed to simply thinking about the regulation itself, allows governments to draw on the wide variety of tools available to them[3]. These range from providing advice, gathering information not available to others, and influencing with economic incentives through to introducing and enforcing legally binding regulations.

> "Governments have a big toolbox. You need to think about the whole spectrum available: from providing advice, information campaigns and economic levers all the way through to actual regulations and their enforcement, which can go from light touch through to heavy handed."
>
> **Nick Malyshev**, Head of Regulatory Policy Division
> Organisation for Economic Co- operation and Development (OECD), Paris

While this review focuses on regulatory systems in which government or its agencies play a leading role, market driven initiatives can also be used (either separately or integrated into the regulatory frameworks). This still needs good design: fear of civil litigations, insurance needs and supply chain demands can have a greater cumulative impact on small businesses than legislation itself[5]. This "blue tape" of business-driven requirements is often perceived as part of the "red tape" of government mandated regulations.

At the extreme, the market may have a greater influence than regulators. High impact, visible events that destroy corporate reputation and value will be penalised by the markets, even for businesses seemingly "too big to fail". Arguably this has played out in the $19bn cost of the 737 Max tragedies reported by Boeing.

OECD principles of good regulatory practice
OECD provides extensive information on international regulatory practices. Its principles for good regulation[4] form the basis of many government practices. They set out an expectation for regulations to:

(i) serve and achieve clearly identified policy goals;
(ii) have a sound legal and empirical basis;
(iii) produce benefits that justify costs;
(iv) minimise costs and market distortions;
(v) promote innovation;
(vi) be clear, simple, and practical for users;
(vii) be consistent with other regulations and policies; and
(viii) be compatible with competition, trade and investment-facilitating principles.

The tools of regulation

Figure 3 illustrates frequently used regulatory tools grouped within three inter-related categories.

Ultimately, the art of regulation lies in making skilful use of available tools, often in combination, while:

- targeting the right issues – preferably before they escalate to major problems – which needs vigilance and an ability to prioritise;
- tackling these issues in a consistent, transparent and proportionate way;
- maintaining sufficient organisational agility to be responsive; and
- securing access to cutting edge science, often with limited resources.

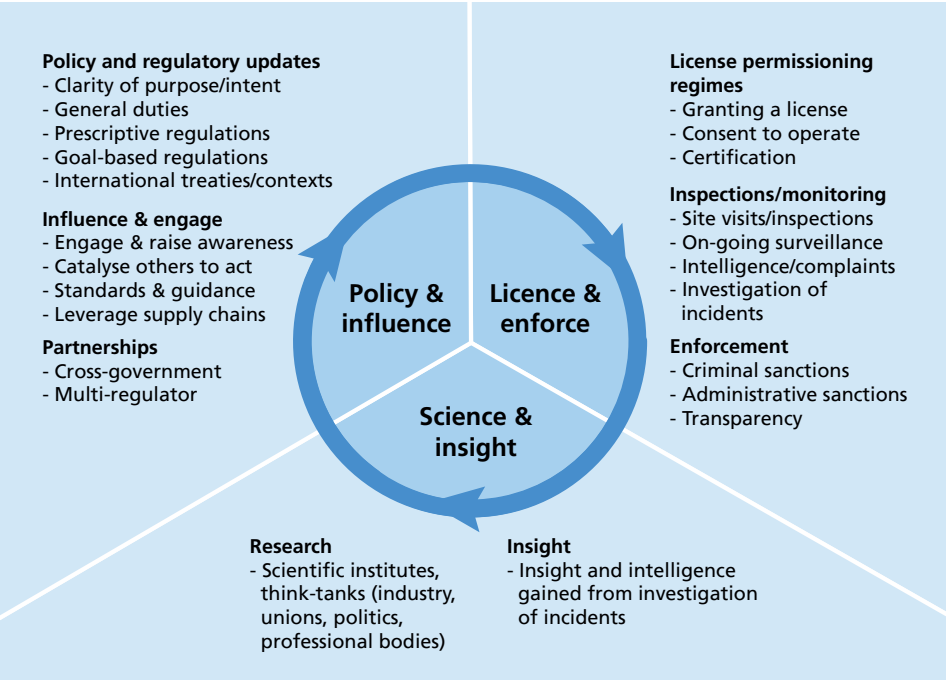

Figure 3: Tools of regulation

Focusing efforts on the most serious harms or risks is the essence of concepts such as "risk-based regulation" and problem-based approaches[6]. There are many attractions to focusing limited regulatory resources in this way, but also practical challenges[7]. These include handling stakeholder pressures when faced with problems that have come up and need tackling, as opposed to focusing on those risks that may be more significant but less immediate.

International practices

Regulation is highly contextual. What works well in one nation may be entirely inappropriate in another.

While generic principles, formal international standards and risk management methods can (and do) cross boundaries, regulatory design needs to account for factors such as the local political and legislative context; societal attitudes (for example to corruption or to compliance), maturity of the system; regulator capacity, capability and resources. Irrespective of these differences, there remains a need for a strong interested impartial regulator, tackling the right issues and with access to effective sanctions.

Regulation design is influenced by differences in legal frameworks. For example, Europe's rule-making system is codified, where there is a comprehensive set of rules that provide legal certainty, while the UK's is based on common law, which examines the context and precedent to determine wrongs. Regulations range from prescriptive rules (where you are specifically told what you must do to be compliant) through to goal-based principles (where you explain how you will meet a defined outcome). Each has its own strengths and weaknesses[8]. In practice, a hybrid design will often blend elements of both prescriptive and goal-based approaches to reduce the risks of harm.

A comparison of transatlantic risk regulation[9] concluded that distinctions in regulation design are less clear-cut than is often stated (and contrary to popular perceptions). Although there are some differences in regulatory approach, the EU and US, on average, achieve similar outcomes. There are individual cases that do lead to different regulatory outcomes but these most often reflect different situational or political contexts.

How compliance with regulations is incentivised, monitored and enforced can be another area of difference. Alongside practical issues such as access to regulatory capability and technology, approaches can be influenced by whether regulation is seen as more of a legal structure, whose violation warrants punishment, or as more of a social norming process that aims to shift behaviours.

Incentives include giving businesses greater freedoms, or fewer inspections, for positive behaviours on the basis that they present fewer risks. Sanctions might range from administrative penalties (such as fines or stopping activities by suspending licences to operate) through to criminal proceedings (with sizeable fines and imprisonment). Reputational levers can be used too: an US OSHA (Occupational Safety and Health Administration) press release is estimated to amplify the impact of its enforcement action by a factor of 200.

How regulatory systems work in different national contexts is influenced by factors such as how regulatory institutions are designed, relationships between governments and major interest groups, explicit and tacit rules for collecting evidence, the use of experts, social attitudes and the degree of public participation. To illustrate this point, a review of chemical plant risk assessments[10] showed how the same science did not produce the same regulatory requirements or outcomes in different nations. This leads to a wider issue: businesses can exploit variations by "forum shopping" in which they find the country with the most lenient regulatory regime for their operations.

Being aware of, and understanding the basis of, international differences in industry practices and standards can also be used to drive continuous improvement. Cross-national comparisons can add value by identifying good practice and sharing learning on approaches that are seen to work well.

Vulnerabilities of regulatory systems

In many countries, regulation has been extremely successful at improving the world around us and saving lives. However, there are failures too – big and small – where serious adverse impacts have been linked to the design or operation of a regulatory system. Examples include:

- **Highly visible disasters** that trigger regulatory reform[11]: *Deepwater Horizon* in the Gulf of Mexico, the leaky homes crisis in New Zealand (timber-framed homes built from 1994 to 2004 that were not fully weather-tight), the 2008 economic crash and associated bank failures in the UK.
- **Impacts of longer term or latent effects** that draw out the challenges of "taking care of tomorrow today"[12]: tackling climate change; the estimated 40,000 deaths annually worldwide linked to use of asbestos; and environmental degradation leading to the loss of native habitat and biodiversity.
- **"Silent killers"** where ineffective, disproportionate or flawed regulations lead to chronic underperformance of a regulatory system or act as a barrier to beneficial innovation. Poor regulatory approaches in different jurisdictions have been cited[13] as having had significant negative impacts on innovation relating to: the regulatory treatment of cell therapy as drugs; regulating bio-pesticides through the chemical pesticide system; and approaches to regulation of genetically modified (GM) crops, organisms and fish.

In preparing for a more disruptive world, there is a need to be aware of vulnerabilities that, either alone or in combination, might heighten the risk of regulatory failure. Potential vulnerabilities are summarised below. In many cases these will have already been recognised and be actively managed. However, history has shown that they can also be only partially, or inadequately, addressed – and potentially lead to regulatory failures.

Regulatory gaps/ overlaps, inconsistencies or unclear accountabilities

A regulatory system with gaps between regulatory powers and intended focus, or with other similar inconsistencies or unclear accountabilities, can cause issues. Such inconsistencies and unclear accountabilities make it harder to enforce the law, can allow businesses to manipulate the system and can undermine the regulator's legitimacy.

These vulnerabilities can result from drifts away from regulatory purpose, or by disjointed additions to a regulatory system over time. They can also arise from defining the regulator's purpose and independence too tightly in law. Although doing so can enhance public confidence, it can also leave the system less able to adapt to changing technologies or business models.

The resilience of critical infrastructures such as water, electricity, transport and communication, that rely on interconnections across sectors, borders or functions, can be threatened when gaps or overlaps occur between the regulators that are responsible for different parts or sectors of these infrastructure systems. . Associated gaps, or competing regulatory priorities, can also be exploited very effectively by pressure groups or businesses to advance their cause.

Power imbalances

Regulatory systems involve complex interactions of politics, power, competing views and many different vested interests. These dynamics (the political economy), power imbalances (wealth/ power loops), and lobbying can lead to situations that have potential to undermine credibility and erode public trust[14].

The link between corruption and regulation in some countries, where bribery is seen as a way of "getting things done", is one often quoted example of how power imbalances can play out. Controlling corruption can be used as a rationale for de-regulation (or not regulating in the first place) but the opposite can also apply: government officials can create regulations as an opportunity for bribes. In practice the question may be more one of how regulations are implemented, as opposed to the regulatory policy itself.

Another example of power imbalances is the ability of wealthy individuals or organisations to enhance their own interests by funding think-tanks or sponsoring scientific institutions that have an influence on the regulatory system. This can create perceptions of "institutional corruption" that can undermine the inherent trustworthiness of an institution[15].

Large organisations (including technology and social media companies) also have the power to establish operating norms, set default standards and control access to valuable data (or even suppress data that shows negative impacts). They can use this to consolidate their market position and create barriers to entry.

Regulatory capture provides the third example given here. This is when the influence gained by regulated industries over their regulator, either directly or indirectly, leads to the regulator supporting industry instead of serving the public interest. This was highlighted in public inquiries following the Piper Alpha and *Deepwater Horizon* disasters: UK and US regulators were each caught between government interests in revenue generation and their safety oversight remit (this has since been changed).

Lack of diversity

Many regulatory policies reflect the values of those making choices and judgements. These can be overly influenced by unconscious biases and by failures to engage people who might bring different styles of problem-solving or who have unique perspectives to offer (for example, the intended beneficiaries of regulation). A lack of diverse thinking limits the creativity and injection of new ideas needed to respond to complex or uncertain conditions.

If the regulatory process is dominated by overly technocratic mind-sets, inflexible organisational culture, personal values inaccurately projected onto others, and intellectual prejudice (blind faith in selected approaches or institutions), then perceptive voices and insight might be missed. A feature of several major disasters, with significant loss of life, has been the failure to listen to those challenging the system or providing warnings of emerging risks. There remains scope to do considerably more by injecting non-expert views on matters that fall into the grey zones between conjecture and certainty[16].

It is not enough simply to bring diverse groups together. Gaining a shared understanding can call for mechanisms that help ensure common language and respectful, constructive debates: bridging different terminologies used in different disciplines, or different mindsets and values, has often proved difficult.

Long term or latent issues

Governments generally prioritise short-term goals and interests over those of a longer-term nature. This happens for a number of reasons that include a human bias towards the present, the deeper uncertainties of longer-term futures and electoral cycles.

This tendency makes it harder to manage latent risks that only become apparent at some distant point in the future (such as occupational disease) or to deal with long term issues where action is needed now but can be deferred (like climate change or preparation for a possible pandemic). The urgent problems of today will tend to divert attention from, and thwart efforts to address, the bigger problems of tomorrow. As a result, future generations may be burdened by the lack of action today. These inter-generational issues may become even more apparent in the future, due to the long-term impacts of pollution and use of natural resources linked to today's global growth of industrialised activities.

Participatory processes of various kinds can be useful for these types of issues by building public understanding, securing agreement on shared goals, and negotiating solutions to complex inter-generational issues. However, the fragmentation and polarisation of attitudes observed within societies makes it even harder to build the consensus or trust that managing long-term issues requires.

Photo by Markus Spiske on Unsplash

Institutional inertia

For regulators, legitimacy and credibility are inter-related cornerstones of regulatory success. Either can be lost through "institutional inertia". Institutional inertia reflects the tendency of long-established organisations to continue with their deeply embedded procedures and systems, sometimes unaware of the extent to which these have become out of touch with changing priorities or circumstances. This can, in turn, undermine the entire regulatory system.

Legitimacy is typically grounded in the laws establishing the system, but also relies on regulators having a social license to operate. Regulatory actions out of line with what citizens expect can lead to erosion of trust; the outcomes have to be something the public accept as fair. Regulators need to be clear and transparent about how they identify and prioritise risks and consistent in how they respond. Within democratic societies this means facing public scrutiny head-on and being open about the complex balancing of risks and resources that regulators do on a day-to-day basis.

Regulator credibility is about how the system is managed. Constraints created by statutory remits, out-dated standards and practices, or misaligned incentives all hamper regulatory innovation and the system's ability to adapt to change. Lack of resources, capabilities or investment in the regulator or its wider government community make this worse: the skills, capabilities and technologies needed in the future will be quite different to those of today.

Knowledge gaps and asymmetries

Regulatory systems rely on trustworthy science and evidence, coupled with knowledge of on-the-ground reality and a level of future foresight, to inform decision making and take appropriate action. In some situations, particularly for emerging technologies, regulators struggle to keep up with the pace of innovation in high tech industry. As the application of technology accelerates rapidly across geographic and sector boundaries, there is no longer time to reflect, review and test the impact of this technology as has happened traditionally. Besides, technology decisions are often made behind closed (corporate) doors, protected by intellectual property rights.

Significant knowledge gaps and imbalances between regulator and industry (knowledge asymmetries) can result in inappropriate regulatory responses (being too cautious, too insular or too trusting). Failure to understand the limits of existing or emerging regulatory tools and practices can also lead to inappropriate responses that escalate issues. Group dynamics can make this worse if creativity and individuality is stifled in order to avoid conflict

and achieve consensus ("groupthink"). This type of behaviour was recognised in the British Academy's review of the 2008 financial crash noted the "wishful thinking combined with hubris" that led to ineffective responses[17].

In practice, the only available expertise may only be available from within the regulated industry itself. In these cases, effective oversight mechanisms and controls are essential to ensure independent scrutiny and transparency. That need becomes even greater for controversial or politically charged innovations.

Failure to learn or to spot warning signals

The ability of industry, regulators and governments to understand what is happening across a regulatory system, to obtain timely feedback and to learn from this, is critical. Yet all too often there is a failure to spot the warning signals of imminent failures or of fundamental changes in the behaviour of the system being regulated. Organisational cultures and closed mind-sets can lead to warning signals being missed – whether from events in different geographies or domains, or from lone voices. This can be further complicated by blurred regulatory boundaries (with gaps or overlaps) that make it harder to determine which regulator is accountable either for spotting or receiving warning signals.

Failure to act on and embed learning is a persistent issue, particularly with the passage of time after an incident has taken place. Even where there is awareness of the issues that are signs of a coming failure (pre-cursors), there can be insufficient action to respond to these[18], to learn from catastrophic events[19] or to conduct the routine reviews of regulatory regimes that would identify such failings[20].

The natural tendency in regulatory contexts is to focus on the negatives (what has gone wrong), particularly as reviews are often triggered by an incident. Much more can be done to identify, share and encourage good practice through routine reviews of regulatory systems and knowledge sharing. This could have substantial safety, innovation and economic benefits for society.

Disruptive futures

Regulatory systems are facing challenges that can be vastly different from what they are designed for or used to dealing with. High levels of uncertainty, the scale and degree of interconnections within and across systems, the pace of decision making, and conflicting societal values can all combine to bring complexity, chaos and contradiction. Under these conditions, traditional methods of regulating may lose relevance and can become dangerous if misapplied.

Regulatory systems are facing challenges that can be vastly different from what they are designed for or used to dealing with

This section characterises the disruptive futures that critical infrastructures may face. By linking these trends to regulatory vulnerabilities set out previously, it highlights the growing risk of regulatory system failures. Without action, the consequences of disruptive futures could be profound if critical infrastructures were compromised, with risks to lives and livelihoods, the social structures and natural systems that we rely on.

Yet in many ways, the future is "the same but different".

The future is the same because of historical parallels: unregulated behaviours in railways or factories at the start of the industrial age compare to those at the frontiers of Ai applications. The ethics of nuclear weapons compare to those of genome sequencing. Innovations and scientific knowledge driven by global pandemics, wars and economic recessions are seen in both the past and the present.

But the future is different too. The global interconnectivity and pace of change enabled by the communication and data networks of the information age has brought new business models and fundamentally changed societal dynamics. With that connectivity comes a range of systemic challenges: conflicting viewpoints and complex trade-offs are more exposed; static, centralised, physical infrastructures and big organisations are shifting to dynamic distributed virtual worlds and individual operators, where innovations can seamlessly move across sector or national boundaries at speeds and scales not previously experienced.

Those differences are intensified by the transition from the industrial to the information age, by the uncertainties and dilemmas that this transition brings, and by the legacies of past industrial practices (such as climate change, unsustainable use of natural resources, societal inequities).

The drive for innovation

The geopolitical and economic undercurrent of innovation aims to secure national competitiveness, with the drive for innovation bringing positive opportunities to tackle global issues such as productivity and resource efficiency; health issues; demographic shifts.

In many cases, innovation will come from the convergence of previously distinct knowledge bases or technologies: smartphones and wearable technologies (health monitors) combine to support the wellbeing of workforces. Similarly, nanotechnology, biotechnology, information technology and cognitive science can combine to improve human performance and productivity in areas such as disaster relief and manufacturing.

There are competing views on how to approach innovation. For some, regulation plays an important role in allowing society to exercise control over unconstrained risks. Precautionary approaches respond to concerns that an unbridled pace of innovation is not always beneficial. For others, innovators should generally be left free to experiment with new technologies and business models as they see fit – a world of "permissionless innovation"[21] where you ask forgiveness when things go wrong, not permission in advance.

Regulators and policymakers can be guided by either approach. Their choice of vision has dramatic impacts on the ways that we work, live, and connect with the world around us. This choice is just one of several challenges that innovation can bring. For example: How do you allow for the huge disparity of global viewpoints on the ethics of emerging innovations? Who manages trade-offs between precaution, innovation and resilience? How do you say "no" to technology once "the genie is out of the bottle"?

A time of transition

Transitions are not new. Over the centuries there have been periodic transitions linked to step changes of governments, society and technology. We are currently experiencing another in the shift from the industrial to the information age.

These times of transition have recently been described as a "postnormal time" (PNT) in which "old orthodoxies are dying, new ones have not yet been born, and very few things seem to make sense"[22]. In these times, uncertainty and recognised ignorance (where we know what we do not know) would be expected to increase drastically, with complexity, chaos and contradictions as dominant themes.

Complexity, chaos and contradiction

Postnormal times[22] are described in terms of the three C's of complexity, chaos and contradiction. These characteristics are created by the new types of problems seen today that 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.

Numerous examples of postnormal conditions and signal events have already been seen. These include:

- extreme weather events, from droughts and fires in Australia to floods in the Punjab region in India
- the scale and speed of growth of invasive species such as zebra mussels in the Great Lakes that led to power plants becoming inoperable
- pandemics such as SARS, Ebola and COVID-19 which can indirectly impact critical infrastructures
- the chaotic potential of the Internet of Things and failures in big data leading to big mistakes
- social media reinforcing fragmentation of societal and intergenerational values, playing out in political elections as well as attitudes to regulation, institutions and trust.

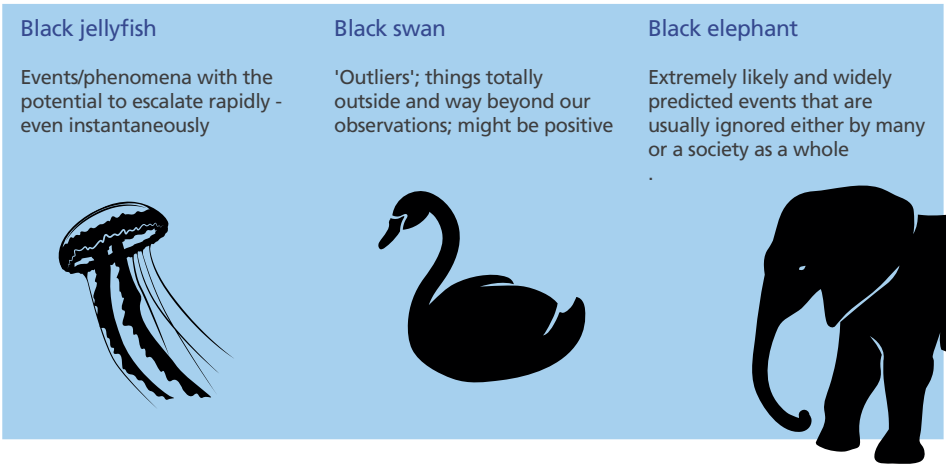

Figure 4: A post-normal menagerie[23]

The "post-normal menagerie"[23] (figure 4) has been used to visualise how major developments can now emerge in wholly different and unexpected ways, with impacts that can be positive or negative. This builds on the widely used concept of "Black Swan" events[24], those things that can come as a complete surprise because they lie way beyond usual observations. The menagerie characterises three different types of events that may not be easy to foresee, but where signals of potential disruption probably already exist. Spotting these signals early can help prepare for their disruptive effects.

Jellyfish are used to show how small things can lead to catalytic events when positive feedback, mutations and interconnections rapidly give them scale. The concept came from jellyfish blooms shutting down coastal power plants to wreak havoc on the electricity grid and society[25]. Other examples include data corruption spreading within highly automated, interconnected systems; single events triggering global public outcry and mass activism to improve human rights.

The high impact elephants are used to describe those extremely likely high impact events widely predicted by experts but that have low credibility with the general public, and hence low public or political urgency for action. Big gaps between expert and public opinion adds complexity and uncertainty to the issue. Examples includes issues like climate change, pandemics, cyber attacks and mental health.

The implications of post-normal contexts for regulatory systems are profound. Alongside dealing with familiar issues, including those latent risks whose impacts are only now felt (for example, asbestos), the challenges ahead will require fundamentally different regulatory approaches and mind-sets.

This is easier said than done. Long established and historically successful regulatory systems and governance structures have to transition too. This brings inherent tensions of the type shown in figure 5. The ability to manage these is influenced by factors such as degree of buy-in for change across the system and the capacity to adapt[26]. Institutional inertia and cultures may prove to be significant barriers.

Figure 5: Inherent tensions to manage

External factors influencing regulatory systems

Technological and societal trends influencing critical infrastructure are widely documented, including in the Lloyd's Register Foundation's own series of foresight and insight reviews[27]. Many of these trends reflect the transition between industrial and information ages (described above), with these new dynamics and the drive for innovation potentially leading to major positive and negative impacts on society.

Interdependencies between society, science and technology bring a variety of new demands and challenges as well as opportunities for innovation within the regulatory system itself. Disruptive forces could significantly affect regulatory systems, and potential impacts of regulatory failures. These forces are summarised below.

Complex interdependent transboundary systems

There are many examples of interdependencies between critical infrastructures – such as electricity, communications and water supply, or in global supply chains – where failures in one system can cascade to the others to create widespread problems.

The interactions between man-made infrastructures and the natural environment provide other examples, with climate change impacts adding a further dimension. Infrastructure failures could be triggered by rising sea levels affecting the world's major cities, or by droughts, fires and floods. They also bring the added complexity of geopolitical issues as harms cross national boundaries.

Interdependencies can operate at multiple scales and cut across existing infrastructure, national or regulatory boundaries. Their complexity can result in deep uncertainty about the behaviours of the overall system, including at what point any significant changes on critical infrastructures cannot be stopped or reversed ("tipping points"). This contrasts with typical regulatory expectations that risks can be foreseen, quantified, controlled and managed.

Data and technology

Traditional sectors are being bridged through the combination of digital technology (to create infrastructure) and data (to create value). For example, sensors and machine learning are increasingly used to enhance the management of water networks and the digitisation of ports. AI also offers scope to boost the efficiency or effectiveness of regulatory systems.

There are downsides such as the digital world attracts criminal hackers at scale, the desire for global technical leadership can drive nationalistic behaviours, and the AI revolution can create social inequities.

Associated challenges include issues such as data quality, openness and privacy (who owns the data, who accesses it, and who uses it), accountability (who is accountable, not only for the direct but also the indirect consequences of innovative technologies?) and the systemic risks posed by platform-based business models that cut across national or regulatory boundaries. It brings new threats in the form of cyber-attacks, social media and other use of technology that could undermine trust in technologies, institutions and businesses, which in itself can leverage or amplify social issues.

Blending the new and the old

The energy and communications sectors demonstrate examples of how infrastructures are shifting towards increasingly decentralised, fragmented and dynamic digital systems. Software tools are driving rapid transformations in network capacity and demand, as opposed to the past that relied on upgrades to hardware to achieve similar results.

This introduction of advanced technologies onto ageing infrastructures brings with it new challenges. There are stark contrasts between the needs of the old (large, static, centralised) and the new (small, dynamic, distributed). The addition of digital components to older assets may shorten the design lives of systems (as systems are used in ways that they were not designed for), add to obsolescence, or may themselves create additional points of failure in individual or interconnected infrastructure systems (with additional sensors that can fail or increasing cyber risk).

The problems of blending old and new can be intensified by mismatches in the knowledge and expectations of the different generations involved in the design, maintenance and operation of infrastructure systems over many decades. Long established operational standards, practices and mind-sets can act as barriers to innovation but can also provide an important perspective.

Competition for knowledge

The pace of knowledge generation can see regulators struggling to keep up with innovation and industry expertise. Industry's greater ability to fund, attract and invest in people increases this knowledge gap, and intellectual property rights mean that many technological aspects remain proprietary to the companies that develop them. The socio-technical nature of future systems requires diverse, multi-disciplinary expertise that can work well together (which is not always the case today).

Information gathering increasingly comes from beyond government, which is intensified when national scientific capabilities are outsourced, as in the case of the US and the UK. Other information sources include global re-insurance firms providing strategic reviews of risk that assist global regulatory systems. Technology also creates new opportunities to gather societal insights, for example through the citizen inputs seen in Asia that is enabled by their digital infrastructure.

Wider sharing of knowledge and public involvement is positive. It also needs clear responsibilities and mechanisms for assuring and protecting the continued integrity of knowledge that infrastructures rely on. This includes securing public access to critical data and knowledge held by the private sector, which can be complicated by over-sensitivities to the data protection laws that now apply in many countries.

Political, economic and societal contexts

Political, economic and societal contexts create three strongly inter-related trends:

Geo-political turbulence can heighten the tensions between technology that now operates at the global level and the geopolitics that influences individual markets – seen, for example, between the US and China and the impacts on the adoption of their technologies. This can reinforce populism and influence attitudes on deeply value laden global issues such as climate change or technology. Regulatory systems may struggle to keep up and be overtaken by how change actually plays out.

Erosion of shared values and fragmented societies as disruptive changes can reinforce inequalities. 24/7 news channels and social media can fuel conflicting views between generations, or between experts and the more sceptical population. While the different perspectives may all be legitimate, the gaps in cohesion can undermine credibility and weaken trust in institutions, contribute to a "blame" culture and hinder global efforts on global issues. Diversity and inclusion, including sustained engagement with beneficiaries of regulation, becomes ever more important.

Economic and budget pressures are likely to rebalance views on the trade-offs between precaution, innovation, resilience. It will add to demands for regulatory systems to become ever more efficient and supportive of innovation. But tightening of funding and resources for regulatory developments also raise questions over who will pay for the investments needed for these new approaches and the potential implications (such as increased potential for regulatory capture).

Implications for regulatory systems

The implications of disruptive change are highly significant. Figure 6 maps the external forces outlined above against the regulatory system vulnerabilities described in the previous section. Comparing the two highlights the risks faced, for example, the future may bring increasingly complex systems that cross boundaries, yet a vulnerability of regulatory systems is their inability to address gaps or inconsistencies that such cross-cutting dynamics might generate. Similarly, rapid industry advances in data and technology can intensify issues seen when there are significant knowledge asymmetries between the regulator and industry.

There are also broader messages that need to be recognised and acted upon:

- What has been successful in the past is often seen as a blueprint for the future. While there clearly are lessons to learn (and to re-learn) from history, previously successful practices may not work in the fast moving and highly interconnected systems of a disruptive world. It will be essential to distinguish between straightforward regulatory issues and disruptive ones requiring a radically different approach.
- Failure to understand the limits of both existing and emerging regulatory tools and practices could lead to inappropriate responses that escalate issues. Disruptive forces could then turn today's vulnerabilities that could be managed into tomorrow's significant regulatory failures.
- These disruptive factors could also be exploited to erode trust in experts and institutions, thereby threatening security and further increasing potential disruption to infrastructures.

This matters. There needs to be greater awareness of the implications of disruptive worlds for regulatory systems and the complex interdependencies we see emerging between society, science and technology. The resilience of critical social, natural and physical infrastructures are at stake with significant potential impacts on lives and livelihoods if they were to be compromised.

Equally, the innovations, ideas and opportunities seen in disruptive technologies and business models could create exciting new regulatory designs and practices – some of which are outlined in the next section.

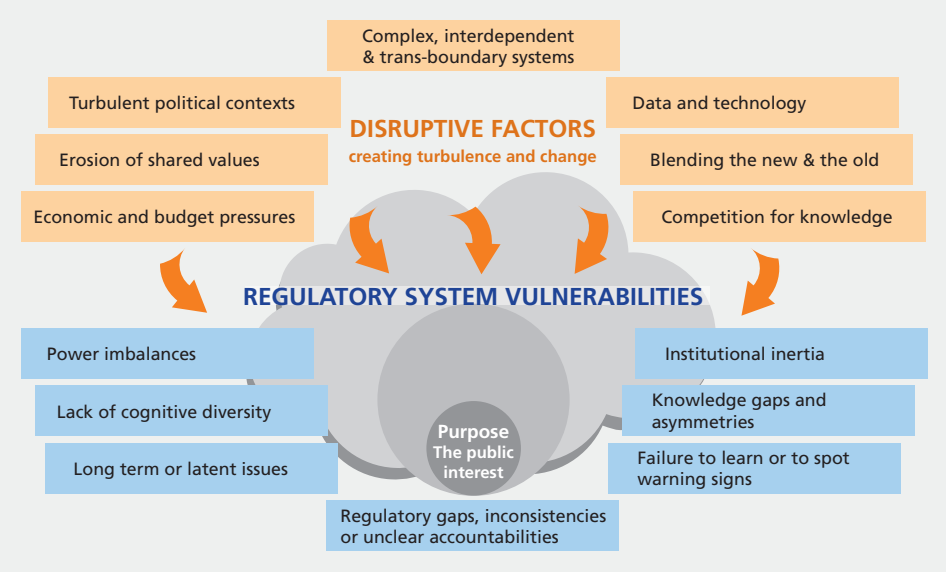

Figure 6: Disruptive future trends mapped onto regulatory system vulnerabilities

Regulatory developments

A variety of regulatory developments are seeking to evolve and complement the suite of tools outlined previously (figure 3, page 18). Many of these aim to exploit the innovations seen elsewhere in business and society.

Proposals include use of novel regulatory models and methods, decision sciences and social interventions, and data and technology. Some are old concepts updated, others new, many are as yet untested.

Designing a regulatory system fit for any future world presents many challenges[28]. All the proposals described below offer potential, but each come with their own strengths and limitations. They often assume that knowledge, values and incentives within the regulatory system align with the intended new ways of working; however that is not always the case. This makes it important to understand the specific contexts, issues or interests that they have been designed to tackle.

> "We are due another intellectual infusion about what regulation should be. Using open data, experimentation through sandboxes, proactive public engagement and making more use of AI by regulators themselves will become more mainstream in almost any future context."
>
> **Prof Sir Geoff Mulgan**, Professor of Collective Intelligence, Public Policy & Social Innovation, University College London

Regulatory models and methods

New regulatory models and methods are being developed to guide the overall design of regulatory systems. These are typically aimed at tackling a specific type of issue, for example how to support business innovation. The overview below groups concepts that share common characteristics and provides a high level explanation of what they are.

A whole-of-system view

The previous section on regulatory systems outlined how achieving desired regulatory outcomes can involve the many organisations and people within the system (the actors) working together to influence behaviours, with this done alongside the more traditional focus on defining and enforcing regulations.

Taking that whole-of-system view forms the basis of the "regulatory stewardship" principles adopted in New Zealand[29]. This sets expectations for regulators to adopt a collaborative approach to the care of the regulatory system(s) within which they work. Doing this can be

challenging where system effectiveness relies on bringing different regulatory functions together and working across regulatory boundaries[30].

Periodic reviews have been implemented as an integral part of regulatory stewardship. These aim to provide the necessary support for new ways of working and for building sustained regulator competence. New Zealand has also taken the distinctive step of formally recognising a regulatory system as a national asset - not a liability – that delivers, over time, a stream of benefits that outweigh its costs.

The emphasis on understanding, and anticipating, the behaviours of the many actors in a regulatory system also features in the concept of "perimeter risk regulation" (proposed in a review of UK electricity regulation[31]). It makes the point that taking a system perspective (by "sitting on the perimeter and looking in") is more important for the regulator than trying to control every dimension of an increasingly complex infrastructure.

A different example of taking a whole-of-system view is seen in a model designed for systems that are themselves changing rapidly, highly complex and unpredictable, and where failure is potentially catastrophic. Guidelines to tackle systemic risks[32] (in which the entire system may fail as opposed to its individual components) emphasise the importance of understanding the system as a whole and any significant risks that it faces. The guidelines highlight the value of open communications and collaboration to prepare for these risks. This might include sharing information (such as early warning signals), as well as co-creating and putting in place mechanisms that would allow the system to adapt and change as issues materialised.

Adaptive models

A number of regulatory models are being developed to create regulatory environments that are more collaborative and more favourable to innovation. They propose iterative methods – where the end goal is defined, and step-by-step, the regulatory design needed to achieve that end goal is progressively worked towards.

These start by defining a vision of what is wanted and possible in the future (the end goal), using methods such as scenario planning to imagine how the future might look. Working back from that end goal can help identify the regulatory barriers, and steps that might be needed to overcome these.

This method is typically applied with a specific innovation or clearly defined development in mind. This is not always possible – under disruptive conditions, for example, the future is unlikely to be predictable and the methods will then rely on looking at multiple plausible future scenarios to explore the "what if" of each.

A frequent challenge in getting to the defined end goal is how to deal with the uncertainties or knowledge gaps associated with significant innovations. One way of tackling this is through experiments. This may include trialling innovations within a controlled environment where existing regulations are relaxed (often referred to as a "regulatory sandbox"). An experiment in Singapore relating to an on-site compact waste gasification pilot, enabled by temporarily relaxing environmental regulations, is one such example.

> "In what conditions can we experiment? Do we accept that there will be mistakes? How do we achieve necessary political and cultural shifts?"
>
> **Prof Silvio Funtowicz**, Professor, Centre for the Studies of Science and the Humanities, University of Bergen

Anticipatory Regulation[33] and Agile Regulation[34] encourage experimentation as part of their approach, with the results of experiments enabling progress towards the adoption of industry innovations. While there is considerable interest in concepts like these, they are relatively new and as yet unproven in many cases[35]. A recently published document, based on the experience and ideas of several nations that are tackling the challenge of enabling innovation, provides detail on these and related ideas[36].

Another way of dealing with uncertainty is through an adaptive model where, step-by-step, regulations can be adapted as knowledge is gained. This iterative approach towards an end goal can be useful for emerging technologies as it allows for caution at the outset, with regulations that are then relaxed over time to safely enable the intended innovations.

Planned adaptive regulation (PAR)[37] makes use of this approach, with one example of its application being the Delta Programme for flood risk management in The Netherlands[38]. A defining characteristic of PAR is its mechanisms to review and potentially revise regulatory policies as scientific knowledge and/ or technological, economic, social and political conditions evolve. Note that data collection and review over time needs a conscious plan and effort from the start.

If regulations are to evolve as knowledge is gained, it is important to consider how adaptation to incorporate this new knowledge might be managed. This includes considering aspects such as frequency of review, scope of impact assessments and how decisions to revise regulations get made[39]. It needs trust that decisions will not get retrospectively reversed downstream and that people anticipating future revisions will not undermine compliance.

The Netherlands Delta Programme
The Delta Programme is an example of planned adaptive regulation, applied to manage risk of major flooding. Its roots stretch back to the 1953 coastal flooding disaster in the Netherlands, the systematic multi-decade response that followed and statutory requirements in 1995 that embedded safety levels and fixed periodic reviews. It brings together social, political and scientific views to enable planned adaptation.

The second Delta Commission in 2007 took this further to introduce concepts such as Adaptive Delta Management (ADM) which identifies long-term options for dealing with deep uncertainty (such as climate related risks), the short term decisions these may need and – importantly – the formal mechanisms to track progress towards the long term goals in order to adapt plans where required.

Strength-based approaches

A regulatory focus on reducing risk can often lead to an emphasis of focusing on weaknesses and what goes wrong. This can be complemented by "strength-based approaches" where attention is given to learning from good practices. Introducing mechanisms to share insights by all actors in the system can add considerable value (in particular from those with first-hand operational experience or the beneficiaries of regulation).

Ethical business regulation[40] (EBR) focuses on the cultures and processes that lead to good outcomes. It encourages consistent reinforcement of "doing the right thing" to enable a learning, ethical culture based upon shared values (which can represent a significant and difficult change for industries where blame cultures are more usual, but can also offer

significant business benefits). EBR is underpinned by mutually respectful, responsible regulatory relationships and fair, honest and open feedback (without seeking blame) to support learning. This has implications for enforcement, and EBR includes a recommendation that different penalties should be applied to those businesses that aim to do the right thing compared to those who fail to implement ethical business practice.

Other approaches encourage more learning from what goes right most of the time as opposed to what went wrong. These methods support the building of resilient processes and behaviours that are better able to deal with unpredictable conditions. More information on these methods, such as Safety II[41], Safety Differently[42] and positive deviance[43], can be read about elsewhere.

Principle based standards

Principle based standards, centred around people and behaviours, are a relatively recent development that build on a long history of formal national or international standards such as those from the International Organization for Standardization (ISO). The guide on Responsible Innovation (PAS 440) published by the UK national standards body (BSI), which includes consideration of ethical and social practices, is one example of a principle based standard.

A strength of formal standards is that they reflect a consensus view of good practice. In general, national or international standards are produced by a group of experts nominated by organisations that have an interest in its use, and informed by wider consultation. Agreement is through consensus of this group of experts to reinforce the authority of the standard and to ensure its acceptance. However, there are risks: the use of nominated industry experts can also raise concerns about vested interests affecting the process. Integrating formal standards with regulatory systems gives scope for consensus-based practices, behaviours and even values (captured in standards) to sit alongside regulatory requirements (captured in law).

One of the concerns about using formal standards in rapidly changing environments is the time taken to develop them. The deliberative processes for making these formal standards can take several years, although fast track mechanisms do exist to address that issue. For example, a rapid, resource-intensive, consensus based development is available in the UK to produce a Publicly Available Specification (PAS). This is similar in nature to a formal standard and can be used to satisfy an immediate business need.

Decision sciences and social interventions

Regulatory systems can themselves take advantage of the growing interactions between society, science and technology. For example, social media can provide new ways of co-creating a shared agenda, communicating compelling narratives to a broader audience and acting as a source of information.

There are many techniques that can be used to provide insight into decision making by individuals and larger groups[44]. Collectively known as "decision sciences", these techniques seek to make plain the scientific issues and value judgments underlying decisions, and to identify the trade-offs that might accompany any particular action or inaction. They include models for decision-making under conditions of uncertainty, experimental and descriptive studies of decision-making behaviour, economic analysis of competitive and strategic decisions, and approaches for facilitating decision-making by groups.

Decision sciences can add considerable value as an integrated part of regulatory design. Their value includes helping to bridge discussions between specialists from different scientific disciplines, and drawing in more varied and diverse contributions (including capturing and explaining citizen or user voices)[45].

There are two key limitations to these approaches:

- As these methods have largely been developed outside regulatory contexts, there are limited governance structures to deal with regulatory applications. Yet the public interest purpose of regulation makes concerns about trust, ethics, data access and risk particularly relevant for these methods.
- The design of social and behavioural interventions, as well as the decisions that these methods support, often rely on expert judgements that draw on both the facts and the values of those involved. Safeguards are needed to mitigate associated pitfalls, such as cognitive bias that can lead to being dismissive of non-experts or being unwilling to listen to those experts who challenge the status quo.

Behavioural insights

The past decade has seen many institutions and governments across the world[46] attempt to apply the ideas set out in *Nudge*[47]. This book argues that the psychology behind decision making (behavioural insights) can be used to design interventions that are less intrusive than the traditional rules often associated with regulation. The idea is that shaping an individual's decision-making environment can influence the likelihood that one option is chosen over another. A key factor is that the individual maintains freedom of choice and feels in control of the decisions they make.

The Singapore government is making extensive use of these methods. Applications range from environmental initiatives (reducing water wastage, optimising use of transport) through to encouraging healthier lifestyles. They are also being used in the UK to improve construction safety: inspections and advisory material can be better targeted by understanding attitudes to safety in small businesses[48].

Behavioural insights can hold promise in particular cases, such as when applied to reasonably consistent target groups[49] as in the construction safety example above. But applications need careful design: government officials and experts are not immune from bias, which can distort how they interpret data and then lead to unintended outcomes[50]. Another fundamental concern is that regulatory use of these tools could result in behavioural manipulation and covert techniques to influence decisions. The repercussions of such concerns could be profound: trust is easier to lose than to gain.

Nudges in Singapore[51]

The application of behavioural sciences in Singapore public policy began with various agencies exploring and learning the techniques through small-scale projects. Working with willing partners who were prepared to try new approaches, these first teams tackled challenges such as increasing the take-up rate of a new pre-retirement planning service.

With over 250 members in a community of practice across 50 public agencies, the use of behavioural insight in Singapore public policy has now evolved to a sophisticated framework of testing and accumulating insights on behavioural interventions. Practical experience has highlighted the need to be very specific about the issue being tackled, and to recognise that behavioural insight is just one of many policymaking tools (its full potential is often only realised when complemented with other analytical methods). There are also cases, such as criminal activity, where legislation and active enforcement may be more appropriate. Ultimately, behavioural intervention is seen as an art that demands acumen, broad consultation and an open mind.

Digital communications

Digital information and communication technologies, ranging from social media to platforms specifically created for public consultations. offer options for gathering insights and introducing "user voice" when designing (and operating) regulatory systems.

There are however potential downsides. The tools can be manipulated, as we see with "fake news" that creates vulnerabilities for democracies. It can also become complex: popular tastes and beliefs can run counter to scientifically based regulation, particularly where people are personally affected by, or fearful of, developments affecting their lives or local environment (it can be seen, for example, in the concerns around the roll out of 5G communication networks and a belief that this affects health).

Societal trust

Societal trust has long been recognised as a key element of regulation. Without trust, regulation becomes difficult to enforce[52] and that can lead to wider social disorder.

Recent research[53] sets out the drivers of trust and distrust on the governance of significant technological innovations (such as AI, nanotechnology, gene editing). It recognises trust as an outcome that is based on perceptions of the trustworthiness of others. It highlights the importance of factors such as regulators being more open, visible and showing positive impact, demonstrably focusing on the public interest (not ideologies), and getting good at ethics, values and stakeholder and citizen involvement.

The research also notes the implicit public trust in the effectiveness of the regulatory systems that allow people to get on with their lives, confident in the belief that risk of harm to people and the environment is managed, and that complex values and ethical trade-offs have been resolved in the wider public interest. Issues arise when the regulatory system is visibly not working well or is at odds with what the public views as "fair". Concerns about regulation can then take a higher profile and diminish public trust.

The impacts of eroded trust go well beyond regulatory systems and can, ultimately, undermine governments. For this reason, damaging trust in the institutions and knowledge bases underpinning regulation (or other government policies) can be an end goal of attacks by terrorists or nation states. Fake news and cyber attacks are examples of this.

> "Intangible infrastructures such as trust are very much part of the critical national infrastructure. A breakdown of trust in institutions or regulatory systems can leverage or amplify a wide range of societal issues."
>
> **Prof Robin Bloomfield**, Partner, Adelard LLP & Professor of Software and System Dependability, City, University of London

Questions around trust are likely to extend into critical infrastructure, as data and technology gets increasingly used to inform operational decisions, to shape demand side behaviours and to track performance (including, potentially, regulatory compliance). This is driving new assurance methods, such as Assurance 2.0, that seek to combine the best of human judgment with the power of computer analysis to support certification of software systems[54]. Alongside the technical challenges, these developments also bring highly complex issues that require ethical consideration – such as who controls the technology, who owns the data, what level of risk is acceptable. They are likely to attract increasingly conflicting views that add to the complexity of regulation and the challenge of sustaining public trust.

Issues also arise in the context of managing long-term (inter-generational) infrastructure or societal risks, raising questions that lie at the heart of safeguarding the interests of future generations[55]. With society and politicians often focused on the short-term, how do you ensure that decisions reconcile the interests of both current and future generations (and make the optimal trade-offs)?

Having made those decisions, how do governmental decision-makers ensure that their successors do not abandon or undermine their efforts due to short-term electoral pressures? Common policy responses include establishing institutions, legislation or financial incentives to serve as means to ensure commitment to policies for the future. The aim is to encourage long-term compliance, but in practice they have had variable impact on reducing short-termism (they are highly context specific). The overall intent – to formalise society's desire to "do the right thing" consistently over time – highlights the need for a collective moral conscience, trust and a political context that values the future.

While many of these big societal issues are beyond the remit of regulatory systems, whether and how they are resolved has major impact on governance and regulatory interventions.

Data and technology (RegTech)

RegTech refers to the use of technology and data science by regulators or regulated organisations to support regulatory oversight or demonstration of compliance (as opposed to the regulation of technology). The technologies include AI, big data, biometrics, cloud computing, and machine learning. This rapidly growing global market is seeing increasing interest in applications beyond its origins in finance.

RegTech offers a wide variety of applications including tracking food origins and tools to identify businesses that present greater risk of harm. A number of pilot studies and trials are underway, but have yet to be fully adopted (see the box on page 48). Developments often involve a combination of technologies and tend to be challenge-led (focused on the problem to solve, as opposed to the technology to apply).

Immediate opportunities, and likeliest area of initial growth, are linked to improving efficiency by using technology to augment what regulators or regulated organisations already do. For example, poor environmental practices in a business can be an indicator of poor safety practices. Technology can connect information on poor environmental practice and poor safety practices, and so speed intelligence gathering to enable timely action on early warnings.

Other potential applications in the near future include making the most of data we already have. Shipping information could be used to demonstrate compliance with maritime regulations, or data from smart meters could be used to manage demand in utility sectors by influencing consumer behaviours.

Improving regulatory efficiency through full automation could add value in targeted applications where human judgement is not required – for example, services where rules on eligibility or calculations are prescriptive, with a clear answer. However, that ease of implementing rules could also bring downsides. When Lord Robens reviewed failings in the UK health and safety system in 1972 , he cautioned: "The first and perhaps most fundamental defect of the statutory system is simply that there is too much law". There will need to be care that the ease of automation does not lead to excessive volumes of regulations and so inadvertently re-create a faster version of this old problem.

Technology could be applied to regulate the digital world: identifying abuses of power through aggregation of personal data; testing for algorithmic bias within decision making systems; or deconstructing a "black box" to make sure that algorithms work as intended. All three examples involve significant technical challenges.

To date, it has proved difficult to step from successful small scale trials of RegTech applications to widespread industrial use. There are questions that go well beyond technology, including who pays for these developments and how to resolve tensions between conflicting objectives (bigger data sets from remote monitoring can support safety but make systems more vulnerable to cyber attack). Other issues include gaining access to proprietary data and legacy regulatory systems, and building confidence in regulated organisations that data will not be misused. Ethics, privacy and accountabilities in complex international systems all add further barriers.

> "Regulators can make much more use of technology. The challenge is to deal with issues such as individual or business privacy. We should avoid being overly-led by what the technology can do, but keep a strong focus on building trust with people."
>
> **Aubeck Kam,** Permanent Secretary, Ministry of Manpower, Singapore

In exploring future use of RegTech, it will also be important to remain aware of limitations such as:

- An over-desire to trust in technology can lead us to overestimating their capabilities.
- While digitisation may be a powerful tool for dealing with increased system complexity, it could also be an aggravating factor that leads to a loss of control in the event of major system failure.

- Data overload and over-reliance on technology can impact decision making, diminish capabilities and abilities to put things into perspective. As information becomes ever more available to regulators, at what point do they become culpable for an accident where they had data but did not take preventative action?

RegTech pilots and trials

The potential for technology is seen in the variety of applications currently being trialled:

- Interpreting legislation: trials are underway to mine existing UK legislation (dating back hundreds of years) to extract requirements for specific industrial sectors. Machine readable laws (legislation-as-code) have been successfully trialled in New Zealand.
- Distributed ledger technologies, such as blockchain, have shown their potential by tracking food through global supply chains, including tracking food origins and safety controls to support international trade.
- Advanced data analytics is enabling better sharing of intelligence and experience between regulators, including applications for identifying and targeting businesses that present great risk of harm.
- Industry trials of technology to assist decisions in safety critical environments, with integrated sensing, advanced modelling and AI. Examples include: drones to reduce the need for people to work in dangerous environments; sensors to monitor crane loading; AI to predict models of risks based on past accidents; wearable technologies to detect fatigue.
- Advanced gaming and virtual reality technologies can transform decision making. Creating simulations of real world applications, such as the "digital twins" that model operation of high hazard facilities, gives the the capacity to drill into detail, to cascade consequences and to develop transformative experiences.
- Crowdsourcing tools to collect and share data, such as the UK platform, Organise, used by workers to share information on working conditions to pressure large companies to improve conditions.

Regulating a disruptive world

For many of the more straightforward regulatory challenges being faced today, particularly where regulatory systems are absent or immature, long established methods continue to be relevant, applied and evolved.

However, at the other extreme, existing practices may not work when faced with high levels of complexity and uncertainty, particularly where there is also rapid change, a need for quick decisions and conflicting societal views. These are the conditions that can characterise issues in disruptive worlds.

In order to apply the right regulatory tools to the right problem, it is essential to be able to differentiate between the many straightforward issues, where established methods work well, and those disruptive issues that require radically different responses.

> "Framing the question at the wrong level can create issues downstream. It is important to take time to distinguish between the conventional and the systemic. In our regulatory agency, 90% of issues were conventional in nature; 9% were systemic and the trickiest 1% looked conventional but were actually systemic."
>
> **Prof Dr Dr Ortwin Renn**,
> Institute for Advanced Sustainability Studies, Potsdam

This section develops a conceptual framework that, developed further, could be used to position issues and acknowledge uncertainties (including any risks of regulatory tools being stretched beyond their limits).

The section also draws out generic attributes that may help regulatory systems cope in such highly uncertain environments and the associated implementation challenges and some of the key questions that will need resolving. These attributes have wider application and value for those governance and regulatory systems dealing with other (less extreme) forms of complexity and uncertainty such as supporting innovation, enhancing resilience or dealing with long term, multi-generational issues.

A spectrum of regulatory strategies

Regulation depends on context. What works well for one type of problem may be inappropriate for another – potentially leading to disproportionate or ineffective regulatory designs. That makes it all the more important to know what works where and when, something that is not always self-evident.

The conceptual framework set out in figure 7 provides a way of visualising and communicating these differences and pinpointing the most suitable type of regulatory strategy. By drawing out both the societal and the technical aspects of the regulatory challenge, it can be used to acknowledge both the level of uncertainty faced and the sophistication of the regulatory strategies that may be needed.

There are also issues that may prove to be almost unmanageable in practice, due to extreme levels of uncertainty or conflicting societal attitudes. These are described as "intractable uncertainties" which need particular care to navigate. In some of these cases, regulation may not be the answer.

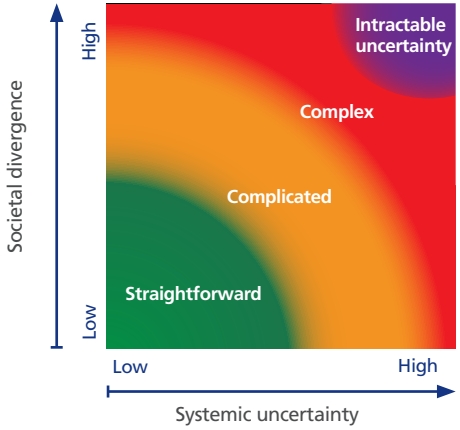

Figure 7: A spectrum of regulatory strategies (based on Funtowicz and Ravetz[56])

The "spectrum of regulatory strategies" considers the issue being regulated in terms its complexity and predictability (systemic uncertainty) and strength of society's agreement on the issue (societal divergence). The model draws on the distinctive framework set out in "post-normal science"[56] which considers interactions between societal and technical elements. It is designed to tackle issues that are changing rapidly and in unpredictable ways, making such problems even harder to control and attracting conflicting societal views on how best to address them.

The axis for systemic uncertainty starts with familiar issues, with low uncertainty, that can be resolved using standard analytical routines and procedures. As new technologies are introduced, and knowledge gaps or variable conditions are identified, uncertainty grows but can be dealt with through professional judgements supported, as appropriate, by research and scientific experimentation.

At higher levels of uncertainty, the issue being regulated may be part of a complex system with extensive inter-connections between its component parts that interact in unpredictable ways. The overall system that needs to be regulated may go beyond a purely technological (physical) system to include natural or societal elements. The extent of uncertainty can be further amplified by pace (of change and of decision making), by scale (crossing regulatory boundaries), by nature (continuous fluidity and volatility) or by long timeframes.

Societal divergence focuses on values, taking account of contested views and dynamic political contexts. The intensity of this scale, as society becomes less cohesive and more divergent, is influenced by aspects such as trust, ethics and social order. These can be amplified by what is at stake (the criticality of the decision).

The axis starts with issues where there is clarity about the nature and extent of possible harm. The public view is cohesive around such uncontroversial issues, so there are also many areas where the public is content to leave the matter to regulators. But further along the axis, societal views diverge to become more divided, with dilemmas for example on long-term or legacy issues. At the highest levels of divergence, there are hotly contested issues that may drive significant activism, present contradictory world views or highlight conflicting international ethical perspectives.

The framework categorises issues to be regulated as straightforward, complicated or complex (with a subset highlighting intractable uncertainty). There are no neat boundaries between these categories, but in general:

- **Straightforward**: the right blend of interventions, with a well framed issue, has a high chance of success. Proportionate, conventional regulations that define what is needed and then control through monitoring and enforcing compliance are likely to be fit for purpose.

- **Complicated**: may involve new knowledge or processes, or bridging regulatory boundaries, but there can be reasonable confidence in the outcome. This may lean more towards goal-based regulatory approaches of the type often seen in high hazard industries: hazards and associated risks are identified, the control measures to manage these risks are defined, and a management system is put in place to ensure the controls are effectively and consistently applied.
- **Complex**: the highly complex systems seen in more disruptive worlds, with their pace of change and inter-connections, means that it may not be possible to predict behaviours or to be confident in control measures. These require problem-solving and regulatory activities different in character and much more adaptive than the kinds generally seen. The attributes needed are outlined overleaf.

Issues with extreme levels of uncertainty (due to either technical or societal factors) may prove to be almost unmanageable in practice. Where these **"intractable uncertainties"** exist, or where the complexity of the system as a whole is not recognised, problems may tip into unregulatable territories. For example, increasing reliance on data and technology brings more susceptibility to cyber attacks, less understanding of the system(s) being regulated and greater ambiguity in ownership and extent of the risks (both direct and indirect). What happens if the cyber vulnerabilities of global systems are exposed or compromised? And who, in practice, would be able to enforce any regulations?

In these cases, awareness of the limits of current knowledge becomes increasingly important, and monitoring of relevant leading indicators of associated risks allows progress with caution[57]. But it may also be that regulation, as typically understood, is not the answer.

Attributes of regulatory systems in disruptive worlds

Under disruptive conditions, regulatory decisions may have to be taken promptly while coping with deep uncertainties about the issue being faced, imperfect information with varied unknowns, and multi-dimensional trade-offs to balance (such as the safety, social, environmental, political and economic aspects).

This will call for a different approach to that used for regulating more straightforward risks, where defining and enforcing rules to control a specific risk may be adequate. At the complex, disruptive, end of the spectrum there is more need to "navigate and adapt" – navigating uncertainty and adapting to the changes happening in the system being regulated. This is shown in figure 8.

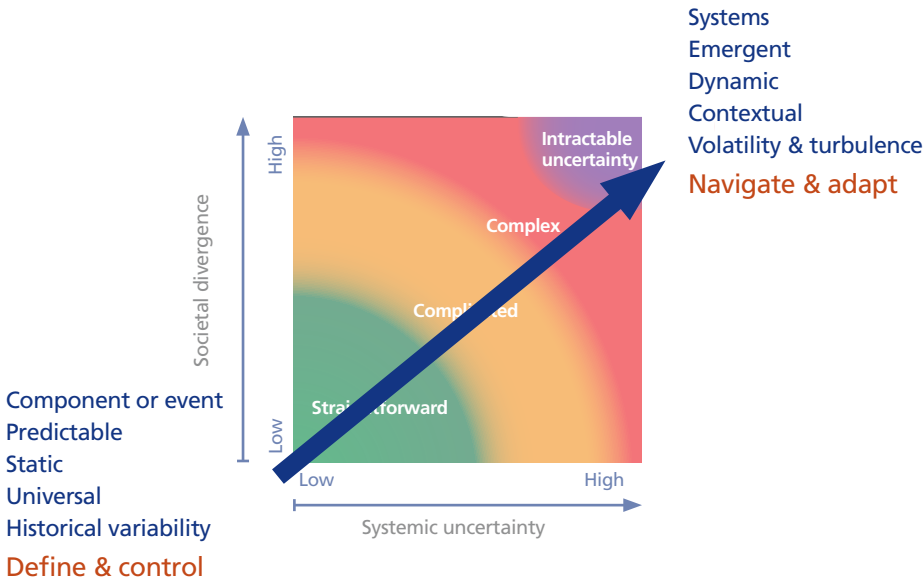

Figure 8: The need for changing regulatory strategies

Desired attributes for regulatory systems dealing with high levels of complexity and uncertainty have been identified from the emerging regulatory methods and the past experience described in previous sections. These have been grouped into three key themes of systems thinking, diversity and adaptive leadership to reflect attributes that are seen as being of critical importance in disruptive worlds.

Systems thinking

Regulatory designs need a whole-of-system view. This means having a heightened awareness for the inter-connectedness between many organisations and people, whose behaviours collectively influence regulatory outcomes, and of the external factors that disrupt (or become disrupted by) how the overall system behaves. This is not easy as system boundaries are seldom clear-cut. Such a system view also allows a broader range of regulatory tools to be applied.

> "People tend to think of risks as isolated threats but the reality is that we navigate a complex interconnected web of risks. As we address one risk, we may affect others. We need to think ahead about multiple consequences."
>
> **Prof Jonathan Wiener,** William R. & Thomas L. Perkins Prof. of Law, and Prof. of Public Policy & Environmental Policy, Duke University

It also means being alert to the realities of a complex and fast-moving system – solving one problem can surface other unexpected issues. More positively, this interconnectedness also means that breaking a complex problem into more manageable components might lead to its eventual resolution. There can be value in tactics that carve out the time and space needed to keep sight of the bigger picture, and retain situational awareness, while dealing with immediate pressures of issues emerging in one part of the system.

Additional mechanisms that enable this system overview, or that provide an overarching capability, may be needed to deal with issues that span several regulators or where there is no regulator in place.

Diversity

Regulatory responses may need to tackle issues from multiple angles. The most complex issues may require combinations of regulatory tools to be applied, for instance, using advanced technologies to monitor what is happening, social norming to shift behaviours, and explicit rules to define and enforce what is needed.

This makes it all the more important to take a system view, to understand the dynamics and nature of the risks being tackled, and to be aware of the limitations of the different regulatory tools that might be applied. When familiar infrastructures and knowledge breaks down, as they might in disruptive worlds, the challenge may well be to recognise that the old ideas and established methods are no longer relevant. There are several examples where not doing so has led to tragic consequences.

It also calls for diversity in the experiences and problem solving styles of people involved, and for the collaborative and inclusive mind-sets that will enable this. When uncertainty becomes the norm, it is important to support co-creation of knowledge (especially across boundaries) and to influence positive action through proactive and open dialogue with actors across the system. Technology can help with this.

Trust can be enhanced by engaging interested individuals from outside established institutions, including the beneficiaries of regulation, who may offer divergent perspectives and new insights. These individuals may not have the "usual" professional or academic background so it is important to recognise and overcome any unconscious biases that may lead to perceptive voices not being heard. That includes putting in place effective deliberative mechanisms to support constructive debate and mutual understanding across a diverse and dispersed group. Generating knowledge is not enough – what matters even more is making use of the rich insights that this type of "extended peer community" can provide.

Adaptive leadership

Adaptive leadership styles can be helpful in rapidly changing conditions. At its core is an ability to anticipate, to listen and reflect, and to adjust responses to emerging issues. As well as relying on trust in the decision-makers this style calls for a level of agility that is rarely found in established institutional frameworks.

Where issues are inherently dynamic and changing, it becomes essential to remain vigilant to early warning signals. Numerous disasters with clear precursor events or warning signals highlight how challenging this is in practice. Fast review, learn, re-design capabilities need to be embedded and periodically assessed. However, the focus should be nuanced. Learning comes not only from failures – also looking at what works well can rebalance regulatory conversations.

A specific risk of navigate and adapt approaches is their potential inconsistency with societal expectations of regulatory certainty and control. For example, "experiments" that trial different responses can be helpful. But some will go wrong, and others may lead to changes. This can be received badly by a society, informed by 24/7 social media, that can often be intolerant of mistakes or perceived "U-turns". This risk is mitigated by public trust, and hence the perceived trustworthiness of key players within the regulatory system.

Trust benefits from actions such as the engagement outlined under diversity above. It also needs an explicit acknowledgement of the uncertainties being faced, the ambiguities and trade-offs that might be involved, and transparent decision making with openness to challenge. That is not easy given the complex interactions, competing views and vested interests of the many people and organisations that may be involved.

Questions to explore

Each theme of systems thinking, diversity and adaptive leadership is simple in theory but complex in practice. It needs clarity, resources and capabilities that may not currently exist, together with strong leadership to get everyone playing their part. While these factors can intensify in disruptive worlds, the associated behaviours are also those needed for regulatory innovation (and, where absent, could prove to be an insurmountable barrier to innovation).

The attributes by themselves do not provide the full answer. There is more to do to share knowledge and understanding of the range of tools available (including their practical application and limitations), and to explore possible solutions to the types of challenges and questions set out in table 1 overleaf.

Table 1: Challenges and questions for regulatory systems in disruptive worlds

Challenge	Questions to resolve
1 Shaping cultural shifts to allow experimentation and adaptive regulatory responses The current age of regulation is based on a blueprint of the future that you can plan, predict, control and manage. In many cases that era is finished. Instead, we have to experiment, measure and adapt, and to gain societal acceptance that there may not always be total control.	• How safe should we be? • Under what conditions and for what types of problem will society accept experimentation? • How do you avoid a political or media blame culture driving future risk aversion when experiments do not work out?
2 Understanding and raising awareness of the uses and limitations of regulatory tools There is demand and scope for re-imagined regulatory systems. Integrating technology, new forms of societal engagement and established tools offer opportunities – but rely on people and trust, good regulatory design and understanding the limits of knowledge/ capabilities.	• What assumptions underpin different regulatory frameworks and tools, and what contexts are they best suited to (individually and in combination)? What are their limits? • How do you secure and retain an essential sense of "shared purpose" in an age of fragmentation and individualism?
3 Combining the old and the new (technologies, business models and knowledge) Introducing innovative advanced technologies or new business models onto ageing infrastructures and legacy systems can be a major challenge. Alongside technical or physical limitations, long established (often successful) standards or operating practices can create barriers to innovation.	• How do you introduce innovative technology, or experiment at scale, onto live critical infrastructure that needs high levels of reliability (for both societal and technical reasons)? • What roles could actors across the whole regulatory system play in enabling the opportunities and mitigating the risks?

Challenge	Questions to resolve
4 Securing institutional memory, access to knowledge and embedding learning behaviours As systems span new boundaries, assuring continued integrity of (often outsourced) knowledge and institutions on which critical infrastructure rely becomes increasingly complex and adds vulnerability. There is need to anticipate need, to capture synergies and to learn.	• How do you retain institutional memory and ensure on-going access to evolving knowledge that critical infrastructure relies on and that gives visibility of early warning signals that drive action? • How do you promote and embed learning behaviours to mitigate major risks and to support sustained improvements?
5 Enabling independent, trustworthy big picture perspectives Many of the biggest issues and risks that society faces span system boundaries, have complex externalities, and bring many competing world-views and conflicting values. Choices and trade-offs in regulatory policies are deeply value-laden and influenced by political contexts.	• What (international) institutional arrangements best protect society's long-term interests and mitigates risks from (for example) wealth/power loops or regulatory capture? • How do you ensure fair regulatory systems when these depend on who is at the table and whose voices are heard?
6 Reconfiguring regulatory systems to reflect the new reality In a world of extreme tight budgets, livelihoods at stake and opportunities from massive systemic change, there will be severe competition for both resources and talent. Reconfiguration will change the balance of human regulators, administrative systems or digital solutions.	• Who is best place to articulate trade-offs between precaution, innovation and resilience? Who regulates the regulators? • What is the regulatory business model – who pays, and for what? What is the optimal balance between deep domain knowledge and system flexibility – how is that achieved?

Findings and recommendations

Disruptive technological, business and societal changes are influencing the highly interconnected social, physical and natural infrastructures of today's world. This review focused on the regulatory implications. These are significant, partly because these changes offer new options that can support innovation and add value to long established regulatory approaches and partly because existing practices may not work when faced with the complexity, chaos and contradictions of disruptive worlds.

The review is unique in drawing together diverse insights on the issues, questions and options that high levels of uncertainty or complexity create for regulatory systems. The findings reflect this breadth:

The review is unique in drawing together diverse insights on the issues, questions and options that high levels of uncertainty or complexity create for regulatory systems

- The changes needed to cope with disruptive worlds are unlikely to happen without first developing a collective understanding of the threats and how these map onto the vulnerabilities of regulatory systems (figure 6, page 36). This includes their impacts to critical knowledge and institutional infrastructures that underpin regulations, as well as to physical networks connecting and providing essential services to communities.

- In practice, not all issues will be complex. The ability to differentiate between the many straightforward issues where established methods work well and the disruptive ones that create radically different demands is a basic requirement. This is not always self-evident. The spectrum of regulatory complexity (figure 7, page 50) provides a conceptual framework that, developed further, could be used to position issues and acknowledge uncertainties (including any risks of regulatory tools being stretched beyond their limits).

- "Navigate and adapt" approaches and mind-sets are required to cope with the dynamics and potentially extreme uncertainties of complex, disruptive worlds. These typically call for:
    - **Systems thinking** – with regulatory designs that take account of the inter-connections between the many organisations and people in the regulatory system, and of the external factors that disrupt (or become disrupted by) how the overall system behaves. It requires mechanisms to deal with issues lying entirely outside existing regulatory boundaries, where there may be no obvious lead regulator.
    - **Diversity** – with regulatory responses that draw on collaboration, diverse thinking and a range of regulatory tools that are combined and tailored to the conditions being faced. As inappropriate responses can rapidly escalate issues and potentially lead to loss of control, this needs deep understanding of the strengths and limitations of any given regulatory approach. It includes overcoming those unconscious biases that may lead to perceptive voices not being heard.
    - **Adaptive leadership** – with an explicit acknowledgement of uncertainty, anticipation of how issues might develop, and the ability to flex regulatory responses in the light of rapidly changing demands or new information. This style of leadership places even more importance on the trustworthiness of key players within the regulatory system.
- Implementation of new approaches will bring many challenges and new questions for regulatory systems, as outlined in table 1 (page 57). Introducing "navigate and adapt" approaches relies on a shift in mind-sets across regulators, industry and society. Action will be needed to overcome deeply embedded attitudes and practices that can act as a barrier to adaptive behaviours.
- The diversity of inputs to this review has reinforced a sense that many of the answers for coping in disruptive worlds already exist – but these inputs also provided examples of how ideas are not being connected and lessons from previous regulatory experience are not being learnt. If regulatory systems are to be re-imagined at the pace required by disruptive worlds, then action is needed to tackle the current fragmentation of critical knowledge and international experience.
- Improved sharing of knowledge and practical experience across national, industry and regulatory boundaries can enhance the pace of adoption for regulatory innovations and can provide early warnings of emerging issues. Such sharing also needs to account for contextual factors such as political and legislative frameworks, societal attitudes, industry or regulator maturity and data access. What works well in one industry, one geography, or for one type of problem may be inappropriate in another – making it all the more important to know what works where and when. There is no "one size fits all".

Recommendations

A theme running through the review's findings is the urgent need to strengthen mechanisms for sharing and curating knowledge, insights and practical experience. This can add considerable value by supporting adoption of innovative regulatory tools and enabling wider preparations for the demands of disruptive worlds.

Given the diversity of inputs that could be involved, spanning nations and industry sectors, a focal point is needed. A "critical knowledge hub" could provide the leadership, focus and energy needed to secure a deep and lasting impact. The review identified three closely inter-related areas as needing early action:

- To establish a trusted, open source, **knowledge repository** that provides a practical and accessible synthesis of available information in the public domain.

  Communicating cutting edge ideas and case studies, together with insights into practical experience, does not currently happen in any systematic way. Identifying, collecting, curating and stewardship of critical information is needed, with value added by providing an overlay of intelligence (such as creating an "early warning network" for emerging issues) and by the global reach that digital media enables. Knowledge that is already accessible could be used to demonstrate value and so help open doors to more restricted sources such as proprietary knowledge protected by intellectual property rights. Information held in the knowledge repository could also provide the basis for compelling stories that socialise the challenges and opportunities of disruptive worlds among key influencers and decision makers.

- To develop **deliberative mechanisms** that allow a dispersed and diverse community to share and debate ideas, insights and different perspectives, respectfully, and to build collective understanding.

  Regulatory systems bring together individuals from very different types of organisations and span a wide mix of disciplines (spanning formal, natural and social sciences), but can suffer from disciplinary silos and different language getting in the way of collaborative work on complex systemic issues. This breadth of perspectives can be further enhanced (and trust built) by engaging interested individuals from outside established institutions, who may not have what is seen as the "usual" professional or academic background. Getting value from these diverse inputs will need the creation of tools and shared language to support effective dialogue and debate ("deliberative mechanisms").

- To compile and maintain a **compendium of regulatory tools**, drawing out strengths, limitations and applications, and insights about future regulatory contexts that these tools may need to contend with.

  Innovative governance, regulatory or risk management approaches are emerging around the world. These add to many options that already exist – but may not be used or combined to full effect – in regulatory design. Providing information on the regulatory tools available, together with their limitations and ideal applications, could enable better regulatory responses in disruptive conditions. Facilitating tests of innovative methods on real world issues could also enable speedier adoption. The information needs to incorporate foresight mechanisms that reflect what can be rapidly changing regulatory contexts.

For the critical knowledge hub to fulfil these strategic ambitions, its identity and behaviours need to be globally recognised as being: independent (of government and industry) and interdisciplinary; participatory and inclusive (to attract fresh voices and gain value from all parts of international regulatory systems); and strongly applied (to connect emerging concepts and knowledge with real world applications and practice).

The opportunity is immense. Connecting discrete and currently fragmented international initiatives that are re-imagining future regulatory and governance systems is both timely and needed. Stewardship and mainstreaming of the associated knowledge can accelerate adoption of new methods and ensure the effectiveness of regulatory systems in protecting lives and livelihoods for the disruptive decades to come.

Lloyd's Register Foundation is well positioned to catalyse action because of its independence of government and industry, and its trusted brand, strong focus on science and technology, and track record of building global coalitions. The Foundation would be able to convene thought leaders, decision makers and practitioners to gain buy-in to what is needed, to shape the detail and to build momentum. In addition, it could use its existing investments as an exemplar of what could be done.

Appendix A: Contributors

We greatly valued and benefitted from the inputs of many international experts, including the following, who contributed through interviews, workshops, discussions and peer reviews.

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