Issue 37 / Spring 2020

RISKworld

The Newsletter of Risktec Solutions

In this issue

Welcome to Issue 37 of RISKworld. Feel free to pass it on to other people in your organisation. We would also be pleased to hear any feedback you may have on this issue or suggestions for future editions.

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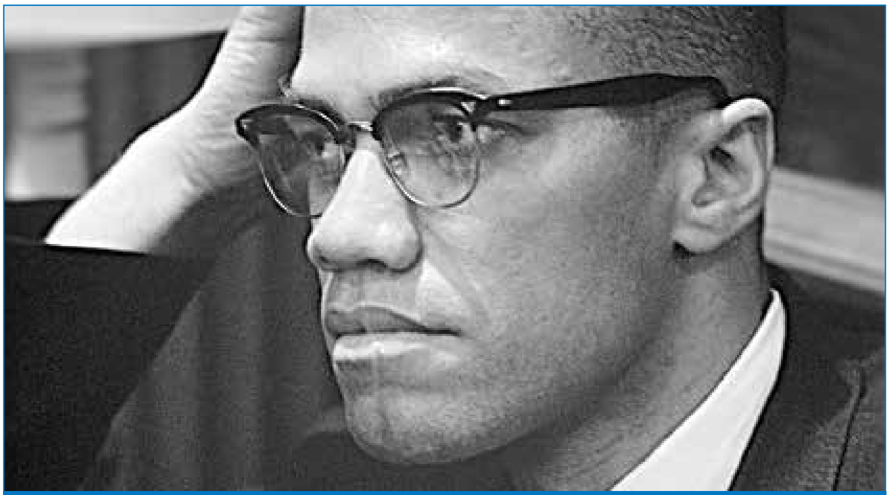
Global adversity or challenge?



"There is no better than adversity. Every defeat, every heartbreak, every loss, contains its own seed, its own lesson on how to improve your performance the next time." Malcolm X

At the time of writing, we all face an unprecedented challenge as efforts to tackle the coronavirus disrupt our global networks and workplaces. Many of us have had to find new ways of working, while key workers around the world are at risk every day doing their best to maintain the essential systems we rely on. At Risktec our main objective is to protect our employees, their families and our clients, ensure business continuity across our global activities and take all actions necessary to help stop the virus spreading further.

On a personal note it has been incredible to see how our employees have pulled together to support one another and our clients during this very difficult time. We have seen many fantastic examples across the business of teams coming up with innovative and collaborative solutions to continue to deliver – some of which are discussed in this edition of RISKworld.

This collaborative approach is also reflected strongly in our latest client satisfaction results covering the second half of 2019. Our overall client satisfaction score increased to 98%, with 99% of clients rating our flexibility and responsiveness as very good or good and 99% of clients saying they would recommend us to other organisations.

Overall, 2019 was a good year for Risktec, set against a highly competitive market and an uncertain global economic outlook. We have continued to grow, develop new services and products which add value to our clients, and open new offices closer to key clients and markets. During the first quarter of 2020, we moved into new, larger offices in central London and west Houston to accommodate our growing teams.

The outlook for 2020 is far more uncertain; no one knows how long the impact of coronavirus will last or how quickly the global economy will recover. Our ability to be flexible and responsive will be more important than ever during these challenging times.

We hope you enjoy all the articles, which are intended to highlight our forward thinking approach. As always, we welcome your feedback and look forward to your continued support. And please stay safe!

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Remote Control – The art of delivering successful workshops remotely

Conventional wisdom has it that structured workshops of a technical nature are best delivered face-to-face in a meeting room with all the technical props and people in one place, interacting dynamically to achieve a common goal. With the coronavirus-related restrictions imposed on travel and social contact, this approach is no longer possible in most countries. Can remote working really offer a viable alternative? And if so, how?

NEEDS MUST

Structured technical workshops, such as might be used for Hazard and Operability (HAZOP), Hazard Identification (HAZID) and Layers Of Protection Analysis (LOPA) studies, have traditionally been delivered face-to-face, with the workshop team sat around a large table, led by a facilitator and recorded by a scribe. Running such workshops remotely was uncommon, and usually only contemplated when the duration was short, perhaps a day or two, and the logistics of bringing together the workshop team were prohibitive, for example, in locations with civil unrest or military conflict.

However, constraints on travel and working practices arising from the global outbreak of coronavirus have necessitated that such workshops cease or run remotely. Whilst the benefits of pressing on are obvious, the concern is that the quality of the output will not be as high as face-to-face meetings and important issues may be missed. To address these concerns, it is worth reflecting for a moment on the factors that make face-to-face workshops successful.

SOCIAL ANIMALS

Face-to-face workshops have been the norm for very good reason – they can be energising, collaborative and productive when facilitated properly. They allow people to interact, discuss issues thoroughly and build synergy.

Physical meetings tap into our innate desire to socialise and our interactions highlight the difference between simply holding a conversation and building a productive working relationship. We all communicate through non-verbal cues: body language, physical contact (a handshake or a hand on a shoulder), laughter, and facial expressions all build rapport and provide context. Without these, communication can feel awkward and may be incomplete. When we meet people face-to-face, we're likely to chat and make small talk, share tea and coffee, lunch – all of which can help build a connection. In a workshop setting, non-verbal cues can be interpreted by the facilitator to assess reactions to concepts and opinions, and ensure the best is brought out of all participants. Similarly, participants will contribute positively and proactively if they feel part of the group and are encouraged by both the facilitator and the non-verbal cues of others.

Around a table, sharing technical information, such as large drawings, 3D models or a live record of findings via projector, is straightforward and inclusive.

REMOTELY GOOD ENOUGH

Whilst remote workshops enabled by digital communication cannot quite live up to these outcomes, particularly in

terms of rapport, technically they can be as efficient and effective if properly prepared and expertly facilitated – see Table 1 for tips and hints. The essential keys to success are to:

- Make all supporting information available electronically.
- Test the host platform before you start, but accept that there may be interruptions in service, and plan accordingly.
- Keep sessions short, so that participants remain focused.
- Adopt a clear participation protocol and make sure this is highlighted at the start of every session.

If these and other tips are followed, there is an argument that remote workshop can be more focused and more productive than corresponding face-to-face meetings. Economically, they are, of course, cheaper because no travel and accommodation costs are incurred. But the key question is whether critical safety issues are more likely to be missed in a remote environment compared to face-to-face? If the participants are the same, the underlying method is the same, the preparation the same (or possibly more extensive) and the facilitation and recording are equally comprehensive, then there is no obvious reason why remote workshops should be more vulnerable to oversights.

CONCLUSION

In the face of unprecedented restrictions on normal working life brought about by the coronavirus pandemic, remote workshops are being adopted as a practical way to make progress. Whilst replicating the richness of social and visual interactions associated with face-to-face meetings is too much to hope for, an expertly planned and executed remote workshop can still deliver a quality, technical outcome.

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PREPARATION

- Ideally, choose a facilitator and a scribe who have worked together previously
- If necessary, hold a pre-meeting to define important preparatory information (e.g. HAZOP nodes)
- Make all supporting information available electronically, well in advance
- Number documentation clearly so that it is easy to refer to
- Limit attendees to the essential minimum, making clear in the invitation who is required and who is optional
- Test the host platform before you start, but accept that there may be interruptions in service, and plan accordingly
- Plan for the workshop to take 25% longer than a face-to-face meeting, but you might not need the extra time

ETIQUETTE

- Check each caller can hear the facilitator (and vice versa) as they enter the call
- To limit background noise, ask everyone to mute their microphone unless they are speaking
- Request that participants disable video to enhance connection reliability
- Ask everyone to identify themselves before they speak, speak clearly and not over one another
- Ask participants to request screen sharing if they wish to highlight specific issues on documentation to the whole group
- If applicable, notify everyone that you will be recording the meeting
- Schedule breaks in advance so that people don't lose focus

FACILITATOR

- Undertake introductions methodically and slowly to allow everyone to capture participants' names and roles
- Identify all supporting information and confirm that it is available to all
- Keep sessions short (up to one hour with four to six in a day), so that participants remain focused
- Control the session – the subject matter, who's talking, who talks next, what actions are needed, etc.
- Park issues (with an action) that rely on additional information or consideration rather than getting bogged down
- Don't be concerned about awkward silences, but be wary of connectivity issues
- Be alert to participants wishing to speak (e.g. by monitoring microphone status or chat room dialogue)

SCRIBE

- Control the worksheet and screen sharing
- As an aide memoire, take a screen shot of the list of participants at each session as displayed by the communication platform
- If you miss or cannot understand something, speak up at a suitable break or message the facilitator
- If people talk too fast or indistinctly, ask the facilitator to remind everyone to speak clearly and more slowly
- Take written notes if this is faster and after each day issue the draft electronic worksheet to all participants
- Review all actions in a separate session with the facilitator and technical leads to ensure they are sufficiently accurate, specific and allocated to the right person
- In the subsequent report, remember to describe the process followed

Table 1 – Top tips for remote workshops

Artificial Intelligence – The rise of the machines

There is an innate fear of autonomous systems able to think for themselves, a fear that Hollywood has tapped into with great effect over the years, with films such as 2001: A Space Odyssey, Terminator and I, Robot. Whilst our worst fears are almost certainly unfounded, as Artificial Intelligence (AI) continues to develop, both in its capability and application, just how worried should we be and what can we do about it?


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In its widest sense, the term AI encompasses computer systems able to perform tasks normally associated with human intelligence, such as visual perception, speech recognition and decision-making. A more restricted definition, which is germane here, concerns the mimicry of cognitive functions, such as problem solving and learning, also known as machine learning. Machine learning can take the form of training by experts or self-learning by exposure to training data (or both), but involves the ability to self-programme in a way that leads to insights or improved performance. And it is this single characteristic that lies at the heart of both the power and the risk of harnessing AI.

THE POWER AND RISK OF AI

AI is already here – search engines, interpreting medical scans, prototype self-driving cars, detection of fraudulent financial transactions, mass surveillance by governments, predicting consumer behaviour, recommending buying choices, and personifying video game characters are just some examples. Likely candidates for AI lie where there are large amounts of input data, some of which may be incomplete or uncertain, and where expert analysis and decision-making is required. Future applications may include air traffic control, driverless transport systems, energy generation and distribution, global manufacturing and supply chains, and the co-ordination of military engagements. Current examples in the leisure and consumer industry are harmless, at worst leading to a poor experience by the end user. But the increasing trial of AI in the healthcare and transport sectors, raises the potential for inadvertent illness, injury or fatality if inappropriately conceived or implemented.

BLACK BOX VS WHITE BOX

In some cases, it may be possible to completely eliminate hazards – for instance, by limiting the motive force of a collaborative robot (or 'cobot') involved in a joint manufacturing task. Where this is not practicable, the key to demonstrating AI safety is the emerging concept of 'explainability' (Ref. 1), which refers to the idea that AI decision-making should be transparent and explainable – the 'white box' approach.

To understand this issue needs an appreciation of the AI's development process. Like a human, the AI learns through experience and feedback; and like a human is influenced by both its training environment and its trainers. In practice, this means that any training limitations and biases may have unexpected consequences in the real world. In 2018 for instance, it was discovered that cancer treatment advice generated by IBM's supercomputer Watson was flawed – the cause was attributed to the hypothetical patient data used for training (Ref. 2). Or, when AI was used as an expert system to advise US judges on sentencing, it unwittingly picked up the historical biases of previous offenders, such as ethnicity and gender (Ref. 3). If biases are known, then training data can potentially be cleansed, but in black box systems, any hidden biases will remain hidden.

EXPLAINABLE AI

These issues can be addressed using the white box approach, where the AI logs the underlying factors involved in each decision. In principle, not only does this mean that during training and real world testing any bias or error in judgement can be corrected, it also means that investigation of real world incidents can firmly establish the culpability of the AI and ongoing improvements can be made.

Of course, designing an AI to be explainable has its own problems. A recent application of AI at Moorfield's Eye Hospital in London speeds up the diagnosis of eye conditions using retinal scans. Cleverly, the system visually identifies the abnormalities used to arrive at its diagnosis, which achieves an accuracy as high as any expert (Ref. 4). What is less clear is how such a system explains a nil result, which is equally important if wrong.

In collaborative safety-critical systems, where a human operator acts as a back-up to an AI control system (or vice versa), as might be employed for train driving for example, it may appear attractive for AI systems to lay out each proposed decision and its reasoning beforehand. For mitigating slowly developing fault conditions, such as reducing maximum speed following the detection of abnormal brake wear, this may be appropriate. For fast-acting situations (such as obstructions on the line), where a rapid response is crucial, there is a clear case for the AI to act without approval. Mixing these two approaches provides another route for erroneous AI decision making.

AI SAFETY ASSURANCE

The fundamental building blocks for demonstrating and maintaining the safe operation of AI systems are well known, at least in outline, since they apply to any software control or protection system:

- Identify and understand the hazards – standard or adapted techniques can be applied to identify the potential impact of component failures (e.g. sensors) and erroneous AI decision making, taking into account training limitations and biases.
- Design ways to eliminate or mitigate hazards, either intrinsically (e.g. by limiting responses physically, or employing redundancy and diversity) or by invoking other systems/operators as defence in depth.
- Design/certify to relevant standards – there are currently no established standards in place for AI safety. The closest available standards are arguably those for functional safety, notably IEC 61508 and ISO 26262, but have significant gaps when applied to AI.
- Demonstrate robustly, but proportionately, that defined safety functions can be met by the AI design, e.g. via its logical modelling architecture, machine learning regime, explainability approach, resilience to faults, processing speed, testing strategy, etc.
- Assess risk both qualitatively and quantitatively against defined safety criteria and consider improvement options – a big issue here is how to predict the reliability of AI decision-making before implementation. One practical way is to rely on the computer simulation of 100,000s of representative scenarios.
- Test as comprehensively as is practicable in a representative (and safe) environment – this may include computer simulation as well as integrated physical testing.

As with any emerging technology the science, techniques, tools and standards ideally needed for AI safety assurance are still developing.

Moreover, with so much progress being made in AI development by so many researchers, it is perhaps too early to expect a consensus on what constitutes best practice. For example, in work undertaken by York University under the auspices of its Assuring Autonomy International Programme, a total of 17 separate approaches to explainability were characterised. Reassuringly, such diversity is probably a sign that developers are serious about building in explainability and serious about building in safety.

CONCLUSION

The future looks set not only to include AI, but to be shaped by it, enabling us to process huge amounts of data and control complex systems quickly and intelligently. Whilst the signs are positive that safety can be baked in from the outset, there remains a good distance to travel before we have all the tools we need to assure AI safety.

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2020 Vision – Clear sight of safety in the design of complex high hazard systems

The modern world is reliant upon complex systems across many sectors – aviation, petrochemical, nuclear power, transport and beyond – each with the potential for catastrophic failure. Surely if given enough time, with enough rolls of the dice as it were, such failure is inevitable?

WHAT THE DOG SAW

In 2009, in his collection of essays entitled "What the Dog Saw and Other Adventures", Canadian writer Malcolm Gladwell wrote of the inevitability of failure of modern and technologically complex systems, in a cogent and well-informed piece that drew upon real-world examples such as the Space Shuttle Challenger and Three Mile Island nuclear reactor disasters.

Gladwell remarks that the investigations and lessons subsequently learnt from such disasters "are as much exercises in self-deception as they are opportunities for reassurance", and referred to a revisionist view that "high technology accidents may not have clear causes at all. They may be inherent in the complexity of the technological systems we have created".

Gladwell addressed in particular the Three Mile Island accident of 1979, which was caused by five concurrently occurring but otherwise discrete equipment failures and events. Notably, this reactor had been the subject of, for its time, an extensive Probabilistic Safety Assessment. This had captured all of the events that ultimately led to a meltdown of the core; but its treatment of dependent failures was less than ideal by today's standards, to the extent the accident sequence was dismissed on low frequency grounds.

The Challenger disaster of 1986 concerns the very different, yet similarly complex, arena of space exploration. Through reference to revisionist sociological research, Gladwell observed that no evidence could be found of the deliberate sacrifice of safety by either NASA or its lead contractors.

These represent just two examples of highly complex systems, engineered from the outset with a keen and necessary eye for safety, where failures nonetheless occurred with catastrophic consequences.

CONTINUOUS IMPROVEMENT

Today's principles of safe design have improved markedly in comparison to those of the time of the Three Mile Island reactor, and Gladwell's rather nihilistic perspective warrants a respectful, robust counter-argument. In the UK, for example, the Office for Nuclear Regulation today demands absolute separation of systems for reactor control and protection, in stark contrast to the approach of the seventies.

Multiple, independent, engineered lines of defence are required to fundamentally halt in their tracks the progression of the most serious sequences of events. Operational controls may support engineered safeguards, but only where necessary. Collectively, lines of defence are designed to preclude the potential for common mode failure of like components, through the introduction of design and manufacturing diversity. In a similar fashion, designs must address the potential for common cause failures, such as might arise from fire, explosion or loss of services, through the provision of separation, segregation and independence of power sources.

KEEPING IT SIMPLE

The effect of applying these design safety principles (see Table 1) is to simplify the complexity of the design at a system level, so that for any given fault or hazard, its progression and the barriers in place

Three Mile Island Nuclear Power Plant

- Multiple, independent engineered lines of defence
- Independence of protection systems from control systems
- Redundancy, separation, segregation and diversity of systems and components
- Use of passive or automatic systems in preference to manual control
- Fault tolerance

Table 1 – Design Safety Principles

to prevent serious consequences are one dimensional – as well as being straightforward to assess. In essence, the design safety principles break the myriad interactions and dependencies that would otherwise characterise a complex design.

To test the extent to which this has been achieved, designs are assessed both deterministically and probabilistically. The first approach uses a conservative set of black and white rules, which embed design safety principles, to assess the adequacy of defence in depth. The second entails the development of a detailed, probabilistic risk model able to examine the influence of any residual common mode or common cause failure (since in practice, these cannot be fully eliminated). The steady evolution since the seventies of ever more powerful computing capabilities has boosted the power of such Probabilistic Safety Assessment. Risk models need not be limited in scope and can cover the multitude of more frequent faults with less immediate consequences that, in the case of Three Mile Island, acted concurrently to create a far worse event.

CHALLENGING CULTURE

Returning to the Challenger disaster, it is noteworthy that the report on the fateful launch by American Nobel prize-winning physicist Richard Feynman, found an astonishing divergence between the risk assessments of NASA's engineers and those of its managers. While engineers reckoned on odds of disaster of roughly one in 100, their management considered it closer to one in 100,000.

In recognition of the ultimate total of two losses over the entire Space Shuttle programme of operations, it would appear the engineering perspective was exceptionally accurate; and arguably it was an endemic cultural failure that led to NASA management not deferring to the expertise of its engineers. Indeed, it is now widely recognised that organisational culture is a crucial factor in the success or otherwise of efforts to maintain safety in complex, high hazard systems. High performing organisations responsible for the design, construction and operation of such systems nowadays must demonstrate that a strong safety culture is embedded throughout all levels of the organisational structure. Arguably it was this key ingredient that was lacking in the NASA of the eighties. A visit to any nuclear power station will quickly reveal how deeply embedded safety-focused culture has become, with no exceptions or privileges offered, regardless of role.

CONCLUSION

As a society we have a choice: we could accept the status quo, and resign ourselves to occasional accidents in complex systems. Alternatively, we possess the capability and culture to apply tried and tested design safety principles – to keep things simple – and undertake meaningful safety analysis to improve designs further. The end result is genuine, evidence-based reassurance that catastrophic failures of complex systems are most certainly *not inevitable*.

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Investing in Safety – The hidden savings of accident prevention

There are many hidden, unrecoverable costs associated with an accident that are much greater in magnitude than most people realise. Looked at another way, there are substantial, unseen savings built-in to accident prevention activities. But what are these hidden costs (savings) and can they be calculated?

INTRODUCTION

Consider these three statements: commercial ventures exist to make money; accidents cost money; effective safety management reduces the likelihood of accidents. If you agree with all three, then it should be self-evident that investing in safety makes financial sense. Indeed, in a proactive health and safety culture, safety management is seen as a net money maker – or even a critical element for increasing profitability – so weighing profit against the cost of safety is actually a non-issue.

Understandably, however, some organisations may require an explicit demonstration that accidents are more expensive than their prevention, before committing to investment. That means quantifying expenditure on preventing accidents, and making a comparison with the savings generated by fewer accidents in the future. Unfortunately, calculating savings is easier said than done.

ACCIDENTS COST MORE THAN YOU THINK

All accidents, whether minor occupational incidents or major accidents, cost money. It is normally straightforward to identify and quantify direct costs, such as emergency response expenses and regulatory fines. But there are often indirect costs which are hidden, less well understood, and seldom easy to quantify.

For example, it may be a simple calculation to work out the direct cost of wages that still need to be paid when an injured employee is off work for a week, but that is just the tip of the iceberg. It is much more challenging to estimate the indirect costs of redistribution of the injured party's workload, the selection and training of a replacement, or even the effects of reduced morale amongst the workforce.

The indirect costs of an accident are typically several times larger than the direct costs; estimates in the literature generally range from 5 to 50 times (Ref. 1). Furthermore, research highlights that the vast majority of accident costs are not covered by

The iceberg metaphor – direct costs are only the tip of the iceberg insurance, with uninsured costs between 8 and 36 times greater than insured costs (Ref. 2). So not only are the hidden, indirect costs by far the largest part of the total cost of an accident, they are also much more difficult to quantify, and mostly unrecoverable.

Viewed more positively, there are hidden savings in accident prevention, and these are much greater than you might think.

ACCIDENTS DESTROY PROFITABILITY

It can be worthwhile calculating the business impact of an incident in terms of the amount of revenue and profit that must be generated to pay for a single incident. The narrower a company's profit margin, the more revenue that must be generated, or the longer the impact on profitability. For example, consider a lost time incident at an onshore drilling rig which usually makes a $10,000 profit each day. With direct accident costs of $200,000 and a (low) indirect cost multiplier of 5, the total cost to the business is $1.2 million, equivalent to 120 days of operation at zero profit!

INVEST IN INVESTIGATION

Accident investigation is ingrained in good safety management practice, where the aim is to find out what happened and prevent recurrence, as well as satisfying corporate, regulatory and public expectations. However, accident investigations do not always assess the costs associated with the accident.

Studies into near misses consistently reveal a pattern: multiple near misses precede most disasters, and most near misses are ignored as cognitive biases conspire to blind managers, e.g. normalisation of deviance and outcome bias. One way of raising awareness of the true scale of the risk/opportunity offered by near misses is to assess the potential costs of these non-harm 'incidents', alongside the costs of actual accidents.

YOUR RISK, YOUR REWARD

Every incident and every business is different and hence, ideally, any cost impact estimate should relate specifically to the company and its place in the market so that it is representative. However, specific data are often not available, particularly if a similar event has not previously occurred. Where necessary, generic cost data published in research reports and by regulators provide a useful alternative, but they generally don't offer much insight on indirect costs.

When asked to calculate the costs of a real accident, assessors can produce huge variability in their estimates – over an order of magnitude. This illustrates the subjective nature of the assessment, and emphasises the need for a standardised cost calculation method underpinned by company-, industry- and location-specific cost data. Online cost calculation tools (e.g. Ref. 3 and 4) provide templates which could be adapted for any organisation's purposes.

COMMUNICATION IS KEY

It is common for assessors to encounter difficulties obtaining relevant information from departments within an organisation. Cost calculation is necessarily a team effort requiring input from multiple parties; effective communication between, and engagement with, those contributors is crucial. The time and effort involved in cost calculation, which can be considerable (and doesn't necessarily scale with the severity of the incident), should also be accounted for in the overall cost of the incident.

CONCLUSION

It is only once the full financial impacts of accidents are understood that the wider value of proactive safety management can truly be understood and communicated in monetary terms. The precise quantification of accident costs can be problematic, but it is clear that such analyses overwhelmingly showcase that good safety programmes deliver a significant return on investment.

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In Japan, battery-powered railcars have been operating since 2014

The Future of Rail Power – The drive for hydrogen and battery-powered trains in the UK

To meet the UK Government's target of net zero carbon by 2050, the rail industry has been set the challenge of replacing all diesel-only trains by 2040 (29% of the current fleet). In addition to extending electrification, the industry's 'decarbonisation taskforce' has recommended the use of hydrogen and battery-powered trains to achieve the Lowest Lifecycle Cost (LCC). But what challenges and risks will these technologies bring to the rail sector?

RAISING STANDARDS

A number of companies, including train manufacturers, Rolling Stock Companies (ROSCOs) and operators, are leading the way in rail-related hydrogen and battery R&D, including a depot-based hydrogen production and fuelling facility. There is clearly the appetite to pursue these options, but currently there are no specific rail standards for the design, installation and operation of the necessary infrastructure for energy storage, refuelling or charging systems. Such standards will be required to safely manage new systems, as well as to standardise their introduction for the optimal operation of the railway.

SAFETY ISSUES

The hazards associated with hydrogen are well understood: notably its propensity for producing flammable, explosive mixtures, acting as a chemical asphyxiate and leading to embrittlement of high carbon metal alloys. Unlike some applications, having hydrogen on-board trains as a fuel source means that the rail industry cannot simply mitigate these hazards by segregation from the general public. Furthermore, the amplifying effects of this fuel source on the consequences of train collisions and derailments will also need to be taken into account.

High energy density batteries present their own hazards. High voltage components and cabling are capable of delivering a fatal electric shock, with some components able to retain a dangerous voltage even when a vehicle is switched off. In addition, the storage of electrical energy has potential to cause an explosion or fire, or release explosive gases and harmful liquids if batteries are damaged or incorrectly modified. Management of these hazards should be driven by cross-learning from the automotive industry, with fleets already in operation, as well as international rail efforts.

GOING GREEN

With the ultimate aim of cutting carbon emissions, it is vital that the environmental impact of these alternatives is well understood and minimised. Clearly, the hydrogen supply should not rely on heavy production of non-sustainable, greenhouse gas emitting 'blue hydrogen' when alternative 'green hydrogen' is available. In Germany, train companies are proposing to use 'grey hydrogen', which is a by-product of industrial chemical processing and might be considered in the UK as a transitional measure.

For batteries, environmental concerns tend to focus on the decommissioning of components and the associated hazardous waste products. The battery industry is beginning to address this issue with manufacturer Northvolt, for example, beginning a new programme 'Revolt' devoted to the recycling of lithium batteries. The decommissioning of batteries should be considered upfront as an integral part of the industry's strategy.

Given the age of the UK's rail network and the staggered manner in which it developed, there are many variations in design across the network. The difference in electrification systems, employing overhead lines and third rail, will directly affect battery charging options, particularly if there is a requirement to be able to use the new rolling stock without route restrictions.

Additionally, there may be limitations on the distance that battery-powered trains can run, which would confine their use to specific routes, though with ever improving endurance this may not be a long-term issue. Nonetheless, recovery measures may need to be devised for stranded trains that lose charge under degraded or emergency conditions. Operations And Maintenance (O&M) will also be complicated by running mixed stock on one route.

SMART FUNDING

Funding has proved to be a big issue in Germany for providing discontinuous electrification to support charging of hybrid vehicles, with companies seeing little investment return. In order to make this transition successful in the UK, any funding scheme needs to take a holistic, long-term view, rather than influence decision-making by focusing on capital costs. Upfront investment will necessarily have to balance the competing requirements of ongoing R&D, new infrastructure (e.g. charging points and hydrogen refuelling) and ROSCOs (new rolling stock with battery or hydrogen powertrains). However, this can be offset against substantial savings, both capital and maintenance-related, associated with eliminating full line electrification. Getting such an integrated approach accepted, approved, and implemented will clearly be key for successful implementation.

LEARNING FROM EXPERIENCE

Prototype hydrogen trains have been operating in Germany for about two years, with filling directly from trailers while a fixed supply station is built. The trial has gone well with no serious incidents and two fleets have been ordered in Niedersachsen and Hessen. In both cases, the rolling stock suppliers are responsible for maintenance and, together with partners from the gas industry, the hydrogen supply. To realise an acceptable LCC, long-term contracts were placed (25+ years).

The roll-out of Battery Electric Multiple Units (BEMUs) – battery electric railcars – is picking up speed, and quickly. Japan and Austria have been operating battery-powered trains since 2014 and 2019, respectively. Three fleets have also been sold in Germany, but are not yet operational. Analysis shows that if the franchise and network is matching to the needs of the technology – including planning, geometry, distance, scheduling, and availability of electrification – this approach is more attractive than hydrogen. A number of infrastructure management issues have been encountered relating to finance and regulatory aspects, which should not be underestimated in the UK's implementation strategy.

CONCLUSION

To achieve net zero carbon by 2050, the UK rail industry has committed to the removal of diesel trains by 2040. Analysis shows that battery and hydrogen trains are viable options in areas where full electrification is not warranted. A key enabler is to ensure that a long-term, integrated systems approach is taken when assessing available options. As such, this should consider safety, reliability and environmental impact, as well as capital and ongoing costs across all railway systems (rolling stock, infrastructure and operations and maintenance).

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