Thetius

Safetytech Accelerator

FATIGUE RISK MANAGEMENT

Applying a data-driven approach to fatigue in the maritime industry

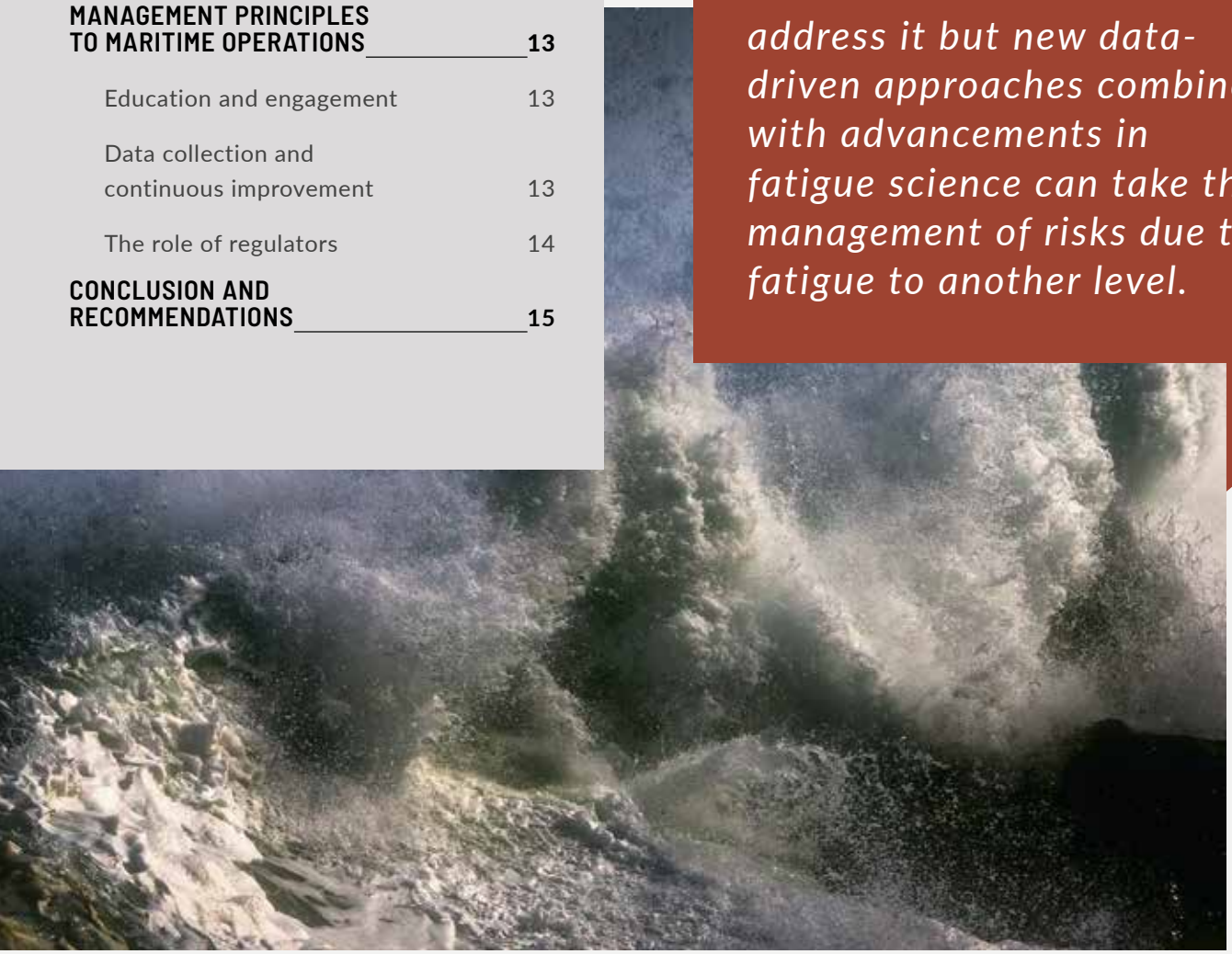
Fatigue has been a problem across the maritime industry for many decades. In years to come, as crew numbers get smaller and ports become more automated this problem will only increase. Solving it requires a new approach to fatigue management.

CONTENTS

FOREWORD

Human error is a leading cause of accidents in safety-critical industries, particularly in maritime, and fatigue is one of the most common root causes.

Fatigue in the workplace is a long-standing issue and much has been done to address it but new data-driven approaches combined with advancements in fatigue science can take the management of risks due to fatigue to another level.



It is to this end that Safetytech Accelerator developed this report in partnership with Thetius. Drawing from applicable examples from various sectors, it illustrates the potential benefits of data-driven approaches to fatigue in the maritime industries, looks into adoption challenges and concludes with a series of recommendations for improvements.

Fatigue in the workplace is a long-standing issue and much has been done to address it but new data-driven approaches combined with advancements in fatigue science can take the management of risks due to fatigue to another level.

It's not difficult to see the direct potential for these technologies to help avoid accidents. It is encouraging to see these solutions are starting to be used in sectors such as aviation and rail. However maritime lags behind - it is clear that much more could be done.

Safetytech Accelerator is a non-profit established by Lloyd's Register and the Lloyd's Register Foundation with a mission to help collaborations to solve major safety and operational risk challenges with enabling technology. Managing fatigue better is among the most important challenges it would like to tackle.

It is to this end that Safetytech Accelerator developed this report in partnership with Thetius. Drawing from applicable examples from various sectors, it illustrates the potential benefits of data-driven approaches to fatigue in the maritime industries, looks into adoption challenges and concludes with a series of recommendations for improvements.

Dr. Maurizio Pilu
PhD, MBA, FIET
Managing Director, Safetytech Accelerator and Vice President, Lloyd's Register

INTRODUCTION

On the 16th of March 2013, the general cargo ship Danio was sailing along the East coast of the UK, having departed Perth in Scotland the previous evening. At 01:00 the Chief Officer, who was alone on the bridge, updated the bridge logbook and plotted the vessel's position on the paper chart. At some point in the next two hours, he sat on the bridge sofa to administer an eye drop for an infection he was suffering from. When he put his head back to ensure that the drop stayed in place, he fell asleep.

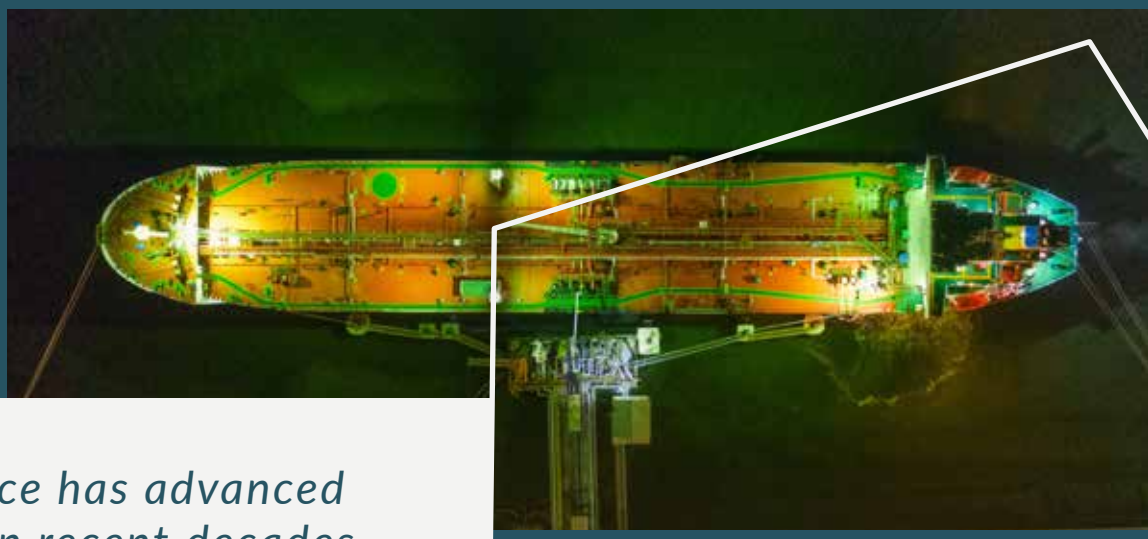
...workers falling asleep during safety-critical operations is an extreme consequence of having a fatigued workforce.

At 03:30 that morning, the Danio struck the rocks off the coast of Longstone Island at a speed of 8 knots. Luckily, no one was injured, but it took nearly two weeks before the stranded vessel could be safely salvaged on a spring tide. The Chief Officer was one of only two deck officers on the ship. He had been onboard for three months and was on a six hours on, six hours off watchkeeping pattern in partnership with the vessel's master.[1]

The grounding of the Danio is one of the more obvious cases of the impact of fatigue on the safety of maritime operations. But workers falling asleep during safety-critical operations is an extreme consequence of having a fatigued workforce. In 2017 Huayang Endeavour and Seafrontier collided in the English Channel. The subsequent investigation found the master of Seafrontier had been watchkeeping on the bridge for 14 hours without a break and though they didn't fall asleep, fatigue likely had an adverse effect on their decision making.[2] Similarly, in 2012 when the vessels Spring Bok and

1 Report on the investigation of the grounding of Danio off Longstone, Farne Islands, England 16 March 2013, Marine Accident Investigation Branch, 2014

2 Collision between Huayang Endeavour and Seafrontier approximately 5nm west of Sandettie Bank, English Channel, 1 July 2017, Marine Accident Investigation Branch, 2018



Fatigue science has advanced a great deal in recent decades. Much has been discovered recently about the impacts of cumulative fatigue, not just on day to day decision making but also on long term health.

Gas Arctic collided, both the master and officer of the watch responsible for the Spring Bok were considered likely to be impaired by fatigue.[3]

Fatigue science has advanced a great deal in recent decades. Much has been discovered recently about the impacts of cumulative fatigue, not just on day to day decision making but also on long term health. To date, very little of that science has been applied effectively in the maritime industry. This problem is further compounded by the crew change crisis caused by the global pandemic in 2020. Maritime workers, both in ports and at sea are key workers who have worked throughout the pandemic. Many seafarers in particular have been forced to work without going home for a period of over twelve months. Increasing our collective knowledge of fatigue is crucial if we are to understand and mitigate the growing risk of an overly fatigued maritime workforce.

This report will explore the impact of fatigue in the maritime industry and compare the fatigue management practices used, both in ports and at sea, with emerging practices from other industries. It will explore the discipline of fatigue risk management, and how this goals-based approach to managing fatigue has enabled operators in safety critical industries to increase productivity while reducing safety and fatigue risks. Finally, the report will discuss how fatigue risk management principles can be applied to the maritime industry, including best practices for understanding fatigue risk, the role of technology in fatigue management, and the role regulators can play in advancing this critical area of work.

3 MV SPRING BOK and MV GAS ARCTIC Collision 6nm south of Dungeness, UK 24 March 2012, Marine Accident Investigation Branch, 2012

UNDERSTANDING FATIGUE

In the short term, fatigue can reduce cognitive ability and impair decision making, sometimes with fatal consequences. Many of the major disasters of the last 50 years have been linked to fatigue including the Chernobyl nuclear meltdown, the Clapham Junction rail crash, the loss of the Herald of Free Enterprise, the New York Colgan Air crash, and the grounding of the Exxon Valdez.

But fatigue is a silent long term killer too; it has the potential to cause problems with everything from work and social relationships to mental and cardiovascular health,[4] and tackling it is critical for the long term welfare and wellbeing of the maritime workforce.

But fatigue is a silent long term killer too; it has the potential to cause problems with everything from work and social relationships to mental and cardiovascular health

COGNITIVE AND PHYSICAL FATIGUE

Fatigue is a complex subject that can be influenced by a wide range of factors including environment, work hours, ergonomics, personal circumstances, diet and health conditions. Though most of us can understand the feeling of being physically tired, our ability to understand and spot cognitive fatigue in ourselves and others is limited.

4 The long-term health effects of fatigue: impacts on mental health, Chisholm, British Airline Pilots Association, accessed 2021

The range of different activities that exist across the maritime industry create a multitude of opportunities for fatigue to cause immediate safety issues and long term welfare issues.

Cognitive fatigue is a type of mental exhaustion, where the mind has been concentrating on a task or set of tasks for a prolonged period of time.

When cognitively fatigued, the brain's ability to carry out high level information processing is severely limited. This is complicated by the fact that the relationship between cognitive and physical fatigue is not necessarily linear. It is possible to be cognitively fatigued without being physically fatigued and, to a lesser extent, vice versa. Evidence suggests that the relationship between cognitive and physical fatigue is an inverse U shape. Achieving optimal cognitive performance requires moderate physical activity, too much or too little and the brain becomes fatigued more quickly.[5]

The range of different activities that exist across the maritime industry create a multitude of opportunities for fatigue to cause immediate safety issues and long term welfare issues. For the most part, ports and ships are operated 24 hours per day, seven days per week. In many roles, the work is physically demanding and anyone who works in a safety-critical role will have to deal with the cognitive load that comes with monitoring and maintaining a safe environment. This is true for workers both on ships and ashore, whether crane operators, deck officers, tug operators, or leadership teams. Though the impact of fatigue is increasingly understood, successfully managing it is another issue.

5 Physical and cognitive consequences of fatigue: A review, Abd el-Fattah et alia, Cairo University, Journal of Advanced Research, 2015

MANAGING FATIGUE

The issue of fatigue in industrial environments is a longstanding one. There is a body of research stretching back more than a century that correlates fatigue with incidents and accidents. One such study, from the American Journal of Sociology in 1912, found that, while the overall risk of industrial accidents is low, it increased by more than 20% for each hour of a worker's shift. Though we have understood that fatigue is linked to accidents for as much as a century, our understanding of how to manage fatigue remains primitive at best.

Fatigue is a physiological state of reduced mental or physical performance capability that can impair an individual's ability to carry out safety critical duties. The causes of fatigue are wide ranging, with a lack of sleep or prolonged wakefulness being the most obvious. But fatigue can also be caused by a short period of intense workload or simply the human body's circadian rhythms.

Generally speaking there are two ways to manage fatigue in safety-critical environments; the first is based on rules and the second is based on goals. The rules-based or prescriptive approach is the most common approach in the global maritime sector, and the goals-based approach has been growing in popularity in other industries in recent years.

For all crew members on ships there are prescriptive rules that govern work and rest hours. These rules are laid down in both the STCW convention and the Maritime Labour Convention. In ports, the rules vary from country to country, with the rules varying wildly based on the local labour and health and safety regulations. That said, most ports and terminals are required to have some kind of measure in place that means that hours of shift or work rostering is done in such a way that it minimises fatigue.

Over the last few decades, a new approach to fatigue management has emerged in industries such as aviation, energy, and healthcare that aims to provide a holistic approach to managing fatigue risks.

This prescriptive approach to fatigue management is a useful starting point. It puts minimum standards in place that all companies can follow and creates a level playing field for all operators across the industry. But it does not properly take into account the myriad factors that can impact an individual's level of fatigue such as their hours and quality of sleep, work duties, personal life, and general health. Over the last few decades, a new approach to fatigue management has emerged in industries such as aviation, energy, and healthcare that aims to provide a holistic approach to managing fatigue risks.

FATIGUE RISK MANAGEMENT: **A NEW APPROACH TO AN OLD ISSUE**

The first principle of fatigue risk management is that fatigue is an inevitable part of work that cannot be avoided. For example, it doesn't matter how well-rested a person is, they will experience some level of fatigue during a night shift due to the human body's normal circadian rhythms.

Indeed, a ship's master may be fatigued after only two or three hours of intense work such as navigating a complex pilotage or high traffic situation. This is before we take into account other factors such as the general health and fitness of an individual, any medication they may be on, or the amount of sleep they actually get during rest period.

But the prescriptive approach to fatigue management does not allow for these factors. Fatigue risk management (FRM) is a methodology that was originally pioneered in the aviation sector, but has since been adopted in other safety critical industries such as road and rail transport, the medical sector, and the energy industry. FRM encourages the development of a risk-based approach to managing fatigue that takes into account issues that go beyond simply the number of hours worked. This includes a range of individual factors such as sleep, diet, general health, the use of drugs or alcohol, and psychological state alongside a range of workplace factors such as shift patterns, leave allowances, equipment design and training.

Successfully deploying fatigue risk management requires the development of a systematic approach to engaging with employees, collecting fatigue data, and managing risks.

Successfully deploying fatigue risk management requires the development of a systematic approach to engaging with employees, collecting fatigue data, and managing risks. According to the International Civil Aviation Organization, a successful fatigue risk management system will provide an organisation with a data-driven means of continuously monitoring and managing fatigue-related safety risks, based on scientific principles and knowledge as well as operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness.[6]

The design and development of a fatigue risk management system follows the same principles as a safety management system; risk identification, assessment, mitigation,

6 Annex 6 to the Convention on International Civil Aviation, ICAO, 2011

The reason fatigue risk management is catching on outside of the maritime industry is that it allows for operators to take a more nuanced approach to everything from shift and leave patterns to training and equipment.

and monitoring. Like a safety management system, a fatigue risk management system seeks to achieve a realistic balance between safety, productivity, and cost and provides a performance based approach to managing risk. Indeed, a fatigue risk management system (FRMS) is designed to share the responsibility for managing fatigue risk between management and individual team members.

FRM OUTSIDE OF THE MARITIME INDUSTRY

The fatigue risk management approach was originally developed in the Australian road transport industry. In 1994, a test run in collaboration with truckers in the Australian state of Queensland found that taking a goals based approach to fatigue led to reduced driver fatigue and increased driver availability.[7]

Since then, the same approach has been trialled and implemented in many different industries with generally favourable results. The New Zealand Civil Aviation Authority became the first aviation regulator to enable operators to develop an alternative compliance system using FRMS principles instead of the prescriptive hours of work approach. In 2011, ICAO, the aviation industry's equivalent to the IMO, amended the Convention on International Civil Aviation to enable the same approach across the world. The amendment, which came into force in 2013, required member states to authorise operators to either work to prescribed flight time regulations, or implement a fatigue risk management system, or some combination of both.[8]

Prescriptive fatigue management rules such as shift time limits are a one-size-fits-all solution to a problem that is different across every organisation. But every operation is unique. The reason fatigue risk management is catching on outside of the maritime industry is that it allows for operators to take a more nuanced approach to everything from shift and leave patterns to training and equipment.

In 2003, low cost European airline Easyjet was struggling to find a balance between the operational needs of their business and the flight time regulations required by the UK's Civil Aviation Authority (CAA). The Easyjet management team believed that the

7 Fatigue Risk Management Systems: A Review of the Literature, Fourie et alia, Clockwork Research, Department for Transport, 2010

8 Ibid 7

On the railways fatigue is a factor in 20% of high risk incidents and the Rail Safety and Standards Board has developed a fatigue risk management framework for all rail operators in the UK.

flight time limitations in the UK forced the airline to adopt a flight roster that actually caused unnecessary fatigue among their pilots. The CAA asked Easyjet to prove that a risk-based approach would work, so the airline funded a fatigue risk management study over two years involving 350 pilots.

The result of the study was the implementation and approval of a new rostering scheme that sat outside of the existing flight time regulations. The new scheme was more productive for the airline, but crucially it produced significant improvements in pilot awareness and a significant reduction in pilot mistakes and non-standard operating procedures.[9]

Though aviation has taken a lead, other industries have begun to take fatigue risk management seriously. On the railways fatigue is a factor in 20% of high risk incidents[10] and the Rail Safety and Standards Board has developed a fatigue risk management framework for all rail operators in the UK. The membership body is now working on a roadmap to have fatigue risk management fully integrated into contracting, planning, scheduling and real time operations on the railways by 2024.[11]

In healthcare there are growing calls for the implementation of a more holistic approach to fatigue management. A series of studies conducted on a population 80,000+ nurses around the world found that working consecutive nights gradually reduces cognitive performance through the week regardless of the number of hours worked, that the number of hours worked in a week is linked to BMI, and that the length of breaks between shifts has a significant impact on long term health. The same studies have also shown that regular physical exercise, structured breaks during shifts, and changes to workplace design such as lighting has a significant impact on the health and performance of nurses.[12]

9 Time to change? Pilots at Europe's fast-growing low-cost carriers are flying more and facing different pressures, Learmount, Flight Global, 2006

10 Keeping the rail industry alert, Basacik, RSSB, accessed 2021

11 CP6 Roadmap for Fatigue Risk Management, RSSB, 2019

12 Improving fatigue risk management in healthcare: A scoping review of sleep-related/ fatigue-management interventions for nurses and midwives (reprint), Querstret et alia, International Journal of Nursing Studies, 2020

THE ROLE OF TECHNOLOGY IN FATIGUE RISK MANAGEMENT

Effective fatigue risk management requires a holistic approach that includes both individual and organisational factors that affect fatigue. This includes training and education for all stakeholders, an ongoing programme of fatigue measurement and the implementation of measures to mitigate fatigue risks. This goes far beyond the capabilities of any one digital tool on the market. That said, there have been incredible recent advances in fatigue science, neuroscience, and artificial intelligence that are making the measurement of fatigue much more accessible and affordable.

One set of technologies that can help with measuring fatigue is wearable devices. An actigraph is a small wrist watch sized device that can measure movement. They have been used for decades in fatigue and sleep studies to measure when the wearer is awake and active, and when they are asleep. By extension it is possible to build a model of how fatigued an individual might be based on their activities. This approach is currently being trialled by UK startups Eupnoos and Workrest. Working in partnership with Shell and Inmarsat, the startups are conducting a trial using wearable devices to measure fatigue among the crew on a tanker, with the insights being used to test improvements to the watchkeeping schedule on board.

Taking this one step further is a new generation of wearable devices that can measure everything from activity levels to blood oxygen levels. The latest generation of the Apple Watch is classed as a medical device in the USA because of its ability to measure critical health factors such as heart conditions[13] Munich based startup Cosinuss has developed an in ear monitoring device that can measure vital signs in real time. The company's technology has been used in a wide range of applications from remote patient monitoring in healthcare to stress and fatigue monitoring in the workforce. In the US, fatigue science startup SmartCap has developed a headband that can be worn under a hard hat to measure fatigue in real time. The band conducts a continuous electroencephalogram to measure brain waves and detect fatigue, alerting operators when they are in danger.

Most fatigue monitoring tools need some kind of external device to function effectively. But recent advances in computational neuroscience have made it possible to measure the cognitive state of an individual using just a smartphone. U.S.-based startup Senseye has developed an application that makes it possible to read the cognitive state of an individual using a standard smartphone camera. By performing a short ocular task, such as following a dot on a screen with your eyes, it is possible for Senseye to determine your cognitive state including stress, mental workload, the presence of drugs or alcohol and fatigue. This approach makes it possible, for the first time, to take an objective measurement of cognitive fatigue in a way that is cheap, non-invasive and uses technology that is already available to anyone.

Technologies such as these allow individuals and employers to work together more effectively to manage risk. Day to day, it is possible to stop workers who are cognitively impaired from doing safety critical work. Long term, for the individual it is possible to understand their own risk factors and for employers it provides a macro-view of the state of the workforce over time, enabling an effective method for understanding the impact of shift design, training, and equipment on fatigue. Over time, there is no reason why these technologies couldn't be integrated into safety or risk management systems to provide an ongoing holistic view of fatigue in the context of the overall risk of an operation.

13 Apple Watch 4 Is Now An FDA Class 2 Medical Device: Detects Falls, Irregular Heart Rhythm, Su, Forbes, 2018

APPLYING FATIGUE RISK MANAGEMENT PRINCIPLES TO MARITIME OPERATIONS

Applying fatigue risk management to maritime operations, whether at sea or ashore requires an employer to be able to engage positively with their workforce. A key part of developing a successful fatigue risk management system is that individuals feel happy to share responsibility for fatigue with their employer and that they feel supported to do so.

The established best practice for achieving this is the development of a Fatigue Action Group made up of stakeholders from across a company including both leadership and operational team members.

The established best practice for achieving this is the development of a Fatigue Action Group made up of stakeholders from across a company including both leadership and operational team members. Further, appointing an individual fatigue champion who can take overall responsibility for the development and implementation of fatigue monitoring and mitigation measures will help to drive these initiatives forward. This could be a member of the QHSE team, but doesn't have to be.

EDUCATION AND ENGAGEMENT

The most important part of any fatigue risk management system is education. Helping individual employees to understand and recognise fatigue in themselves and others is critical in helping to reduce the risk of fatigue related incidents. But education must also be coupled with a positive reporting culture. Similar to the development of a positive reporting culture for safety issues and near-misses, so too should a reporting culture be developed that allows individuals to feel comfortable reporting their own fatigue and reporting it in others on their team.

In a workforce that can be spread around the world with limited communications, achieving the above can be incredibly challenging. But the range of tools available to the industry to enable both seafarer education and better safety reporting is growing. For example, Danish startup Scoutbase has developed an anonymous reporting tool that is being used by Shell and DFDS to collect human factors data with the aim of enabling interventions before an incident happens. Ocean Technologies Group has invested heavily in the development of an integrated seafarer education platform that includes augmented and virtual reality alongside traditional learning that is accessible both on land and at sea.

The most important part of any fatigue risk management system is education. Helping individual employees to understand and recognise fatigue in themselves and others is critical in helping to reduce the risk of fatigue related incidents.

DATA COLLECTION AND CONTINUOUS IMPROVEMENT

Though education and effective reporting will go a long way to improve fatigue management in the industry, effective data collection is required to enable management teams to get a true understanding of the risks and put proper mitigation measures in place. Fatigue data can be collected simply through regular reporting from crew. A range of basic tools exist, such as fatigue reporting forms and self assessment checks that individuals can carry out. But emerging technologies such as Senseye's cognitive assessment tool are providing a new way for both individuals and management teams to get a truly objective measure of fatigue across an operational environment.

With the right data collection in place, it is possible for a Fatigue Action Group to truly understand where and when fatigue risks are highest in an operation and put in place the right mitigation measures. This approach aligns closely with the Plan, Do, Check, Act style of continuous improvement that is widely adopted across the industry through safety management systems. An organisation that wants to implement a full fatigue risk management system should focus on ensuring that over time it becomes fully integrated with the safety management system.

THE ROLE OF REGULATORS

The major barrier to the full adoption of fatigue risk management principles is the current set of regulations that exist across the industry. For ports and terminals, this comes down to national regulators. Some bodies, such as the Health and Safety Executive in the UK, provide clear frameworks for the introduction of a risk based approach to fatigue and others take a more prescriptive approach. For ships, the regulations are laid down in multiple multiple international conventions including STCW and the MLC.

It is unlikely those regulations will change in the near future, but thought should be given to how a risk based approach can work within the prescriptive framework that exists today. Further, there should be an examination as to whether legislation should be changed to enable operators to apply to their flag administration to implement a fatigue risk management system instead of the traditional work/rest hours monitoring system.

With the right data collection in place, it is possible for a Fatigue Action Group to truly understand where and when fatigue risks are highest in an operation and put in place the right mitigation measures.

CONCLUSION AND RECOMMENDATIONS

Fatigue has been a problem across the maritime industry for many decades. In years to come, as crew numbers get smaller and ports become more automated this problem will only increase. Solving it requires a new approach to fatigue management.

There is zero doubt that the maritime industry is increasingly out of step with other safety critical industries when it comes to fatigue.

There is zero doubt that the maritime industry is increasingly out of step with other safety critical industries when it comes to fatigue. Other safety critical industries such as aviation, rail and energy are increasingly moving to a model of fatigue risk management, where fatigue is recognised as an inevitable risk that has to be properly managed.

There are many reasons for maritime being so far behind but principle among them is the lack of flexibility provided by current legislation and the lack of investment in the application of fatigue science to the maritime industry. But for operators of ports, terminals, and ships there are a number of ways to improve fatigue management and therefore improve safety.

Employers should bring together a Fatigue Action Group made up of stakeholders throughout the organisation to address fatigue related issues and take steps to help individuals understand how to spot fatigue in themselves and others.

For those operators who want to go a step further, the full development and implementation of a fatigue risk management system that is integrated with the safety management system is the best way to fully embrace fatigue risk management principles.

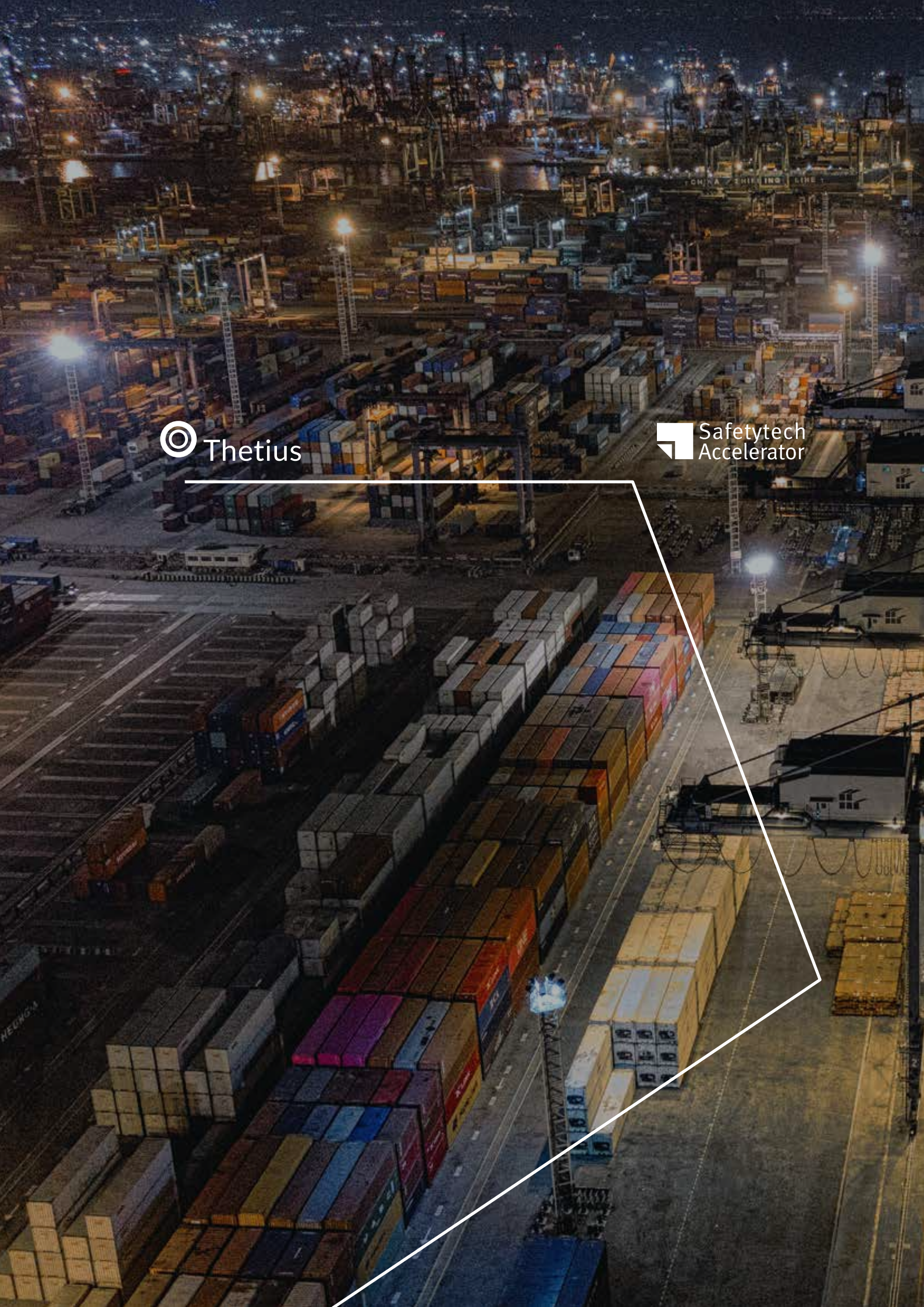
The most important area of improvement for fatigue management in the maritime industry as a whole is employee education and engagement. Employers should bring together a Fatigue Action Group made up of stakeholders throughout the organisation to address fatigue related issues and take steps to help individuals understand how to spot fatigue in themselves and others.

In line with education, there should be a proper fatigue monitoring and reporting system in place for an organisation. This doesn't have to be expensive or high tech. It can be as simple as a paper fatigue reporting form and a procedure for self-reporting fatigue. For those operators who want to take a more data driven approach, there are a growing range of options including wearables and the use of fatigue monitoring systems such as the one developed by Senseye.

For those operators who want to go a step further, the full development and implementation of a fatigue risk management system that is integrated with the safety management system is the best way to fully embrace fatigue risk management principles.

That said, the approach can only go so far without proper engagement from regulators. The IMO has issued guidance on fatigue in the last three years.[14] But the level of engagement on such a critical topic from the regulator does not go far enough. Further scientific research into the impact of fatigue risk management in the maritime industry needs to be conducted. Based on the results, the IMO and national administrations should explore enabling a more flexible, goals based approach to fatigue management. Failure to do this will mean the maritime industry will fall further behind its peers, with lives ultimately put at risk.

14 MSC.1/Circ.159824, IMO 2019


Thetius
Safetytech
Accelerator