IntechOpen

Accident Analysis and Prevention

Edited by Murat Darçın

Accident Analysis and Prevention

Edited by Murat Darçın

Published in London, United Kingdom





Supporting open minds since 2005







Accident Analysis and Prevention
http://dx.doi.org/10.5772/intechopen.78841
Edited by Murat Darçın

Contributors
Peter Vidmar, Paul Smith, Heather Carnahan, Stefanie Martina, Gal Ziv, Elizabeth Sanli, Thaddeus Ulzen, Murat Darçın, Caner Filiz

First published in London, United Kingdom, 2020 by IntechOpen
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, 5 Princes Gate Court, London, SW7 2QJ, United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

Accident Analysis and Prevention
Edited by Murat Darçın
p. cm.
Print ISBN 978-1-83881-961-3
Online ISBN 978-1-83881-962-0
eBook (PDF) ISBN 978-1-83881-963-7

Meet the editor

Murat Darçın is an Associate Professor at the Gendarmerie and Coast Guard Academy, Turkey. He received his Ph.D. from Gazi University, Ankara, Turkey, Department of Environmental and Technical Research of Accidents in 2006. His main research interests include accident analysis and prevention. His research focuses on working conditions, quality of working life, traffic accident analysis and prevention, and occupational health and safety. Darçın has over 100 scientific publications in the field of accident analysis and prevention.

Contents

Preface

Accidents are inevitable in our lives and affect us in many aspects ranging from economical to social, health to legal. While it is not possible to remove accidents from our lives completely, it is possible to develop new techniques or set new standards or prepare contingency plans to reduce their possibility of happening or to alleviate their consequences. This book, aiming to enlighten our ways to prevent accidents, is a compilation of articles authored by reputable international academicians from different prestigious academic institutions in Canada, Israel, Slovenia, Turkey, the United Kingdom, and the United States of America.

The chapters forming this book provide the reader with contemporary information. While the topics of these chapters are related to accidents and their prevention, they also approach the accident phenomenon from different aspects.

The first and introductory chapter, *"Analysis and Prevention of Accidents"*, starts with a depiction of a traffic accident. Then it provides numbers related to traffic accidents such as casualties, budget losses, damaged vehicles etc. Later, the chapter suggests that most accidents stem from human related issues such as distracted driving, fatigue, drunk driving. After that, the chapter goes through the analysis of accidents. Finally, it opens an argument on the use of autonomous vehicles and their possible positive effects on the reduction of traffic accidents. As a conclusion, to prevent traffic accidents, the author of the chapter recommends development of high standards for licensure of drivers, strict implementation of traffic regulations, increasing public awareness and promotion of public transportations as the best means.

The second chapter, *"Attention Deficit Hyperactivity Disorder (ADHD) and Other Neurocognitive Factors Contributing to Road Traffic Accidents (RTA)"*, suggests that while traffic accidents stem from different factors, neurocognitive driver function causes about 25% of most accidents. In this regard, the second chapter investigates the most common disorders that contribute to traffic accidents. These disorders can be listed as follows: attention deficit hyperactivity disorder (ADHD), specific learning disabilities such as dyslexia, autism spectrum disorder (ASD) in adolescents and young adult drivers, and mild cognitive impairment (MCI) and dementia in older drivers.

The second chapter discusses the features of these disorders and how they impair driving along with evidence-based treatments and interventions. The author suggests that increasing awareness of these disorders, screening for them, and offering treatment when appropriate can contribute to reduction of traffic accidents. On the other hand, the lack of attention to these disorders within the road safety disciplines also constitutes a significant problem that must be handled with attention.

The third chapter, *"Can Autonomous Vehicles Prevent Traffic Accidents?"*, handles traffic accident causes, and approaches them from different aspects. According to the author of the chapter, and from a positive perspective, AVs will contribute to traffic safety, increase economic and social benefits, and contribute to environmental protection. However, from a negative point of view, AVs would be hacked, expose our data to third parties, cause liability problems, increase carbon emissions into the atmosphere, risk our health, and constitute a financial burden in economies. The chapter also gives general information on the history of AVs with a general description of them and explains how AVs work. Then it lists the concerns regarding AVs with the pros, cons, moral and legal issues of AVs.

The author of the chapter suggests that AVs are more advantageous than human drivers, because AVs easily obtain and maintain situational awareness, never feel fatigued, and never work under the influence of alcohol. However, while AVs seem better off than human drivers in terms of safety, there is not yet a global consensus on the safety level of the AVs. Aside from a global level, even at a national level, it is hard to find a common ground. This chapter also shows how expectations from AV safety levels differ from country to country. Finally, the chapter implies that if AVs are tested, and the test data are shared, processed, and used for improvisation globally, it is more likely for AVs to be developed and to become more effective in the prevention of accidents.

The fourth chapter, *"Novel Approach in Tunnel Safety Assessment",* studies the conditions that are developed in the event of an accident with a fire in a road tunnel and presents a complexity of fire scenarios with different tunnel ventilations and fire forces using computational fluid dynamics (CFD) simulations. From the point of view of the tunnel manager and rescuers, the methods of tunnel control in crisis situations are most often based on the experience of operators and crisis plans, which are also made by experience or using simple calculation tools. The chapter presents the methodology for integrating methods of rapid processing of risk assessment with time-consuming CFD methods for analyzing the consequences of fire in the tunnel safety assessment process. Although the process for CFD calculation is time demanding, the author of the chapter believes that taking such time is important, as it provides more reliable results and better support for the decision-making in the selection of effective risk control options.

The fifth chapter, *"Simulation Fidelity and Skill Learning during Helicopter Egress Training: The Role of Vision",* aims to evaluate the effects of ambient lighting during practice and performance of simulated helicopter escape sequences. The chapter provides its readers with the results of an experiment where trainees were divided into three groups depending on the light setting of the environment, and then were asked to perform escape sequences. The results of the study showed that training in the light is suitable for potential performance in the dark.

The sixth chapter, *"Scaling Accident Coping Strategies and Testing Coping Capability",* aims to outline the basis for a systematic and consistent process for modelling civil emergency response. The framework of this process consists of assessment of the risk of occurrence, judgement if the assessed risks are acceptable compared to society's benefit, and ultimately provision of a generalized emergency service that will try to mitigate the consequential impact. In other words, this chapter studies and tests whether the preparedness, response and recovery capability is adequate and then presents a new paradigm for accident management, involving the need to quantitatively scale accident and disaster coping strategies and capability.

Through different perspectives, accident phenomenon has been handled from different aspects. Thus, the reader will be provided with up-to-date information and recommendations regarding the elimination or alleviation of the consequences of accidents. Finally, I would like to express my appreciation to the contributors of this book for their invaluable efforts to complete this book.

Dr. Murat Darçın
Gendarmerie and Coast Guard Academy,
Ankara, Turkey

Chapter 1

Introductory Chapter: Analysis and Prevention of Accidents

Murat Darçın and Caner Filiz

1. Introduction

A highly damaged car is pulled off, while another salvage one is across it. Police cars parked with blue and red top lights are on. One paramedic is zipping a “full” body bag, while the other two are carrying a victim to the ambulance in a hurry. Crumbled headlight glasses and leaked radiator liquid are all over the lane you drive through. You both avoid those on the ground and try to see what has happened a short while ago. At the same time, your eyes catch a police officer staring at you. He is waving his hand to make the traffic flow.

This is an unfortunate incident; however, it is a familiar scene we faced at least once in our lives while driving on the road. According to the World Health Organization [1], every year 1.35 million people die all over the world because of traffic accidents, while some 20–50 million people survived with nonfatal injuries; however, some of them still become disabled. A press release [2] by the US Department of Health and Human Services’ Centers for Disease Control and Prevention suggests that in 2012 more than 2.5 million people visited emergency rooms of hospitals because of traffic accidents. However, this is only one facet of the traffic accident phenomenon.

Another report of the U.S. Department of Transportation’s National Highway Traffic Safety Administration [3] provides a detailed cost analysis of accidents that occurred in America in the year 2010. According to this report, almost 33,000 people lost their lives, 3.9 million were injured, and 24 million vehicles are damaged as well. The report analyzes and groups the traffic accidents’ nine pecuniary consequences under two categories: costs related to injury cases and expenses related to noninjury cases. The former consists of medical care ($ 23.4 billion), emergency medical services ($ 1 billion), market productivity ($ 57.6 billion), household productivity ($ 19.7 billion), insurance administrations ($ 20.6 billion), workplace ($ 4.6 billion), and legal costs ($ 10.9 billion), and the latter consists of congestion ($ 28 billion) and property damage ($ 76.1 billion) costs. Altogether, the accidents’ financial burden on the US economy reaches $ 241.9 billion. The percentages of these costs are shown in **Figure 1** [3].

As seen so far, traffic accidents cause not only personal losses but also a significant burden on the gross domestic product of states. To avoid these consequences, each country develops and conducts its own policies and programs. While most of the causes of accidents look the same and can be handled together, in fact, the traffic accidents’ causes differ from state to state with regard to its level of development.

The Korean Road Traffic Authority defines the causes of traffic accidents as unsafe factors, unsafe road environments, insufficient driver knowledge, failure to recognize the danger, and improper thinking [4]. The Government of Jharkhand’s Transport Department lists the causes of traffic accidents as overspeeding, drunken

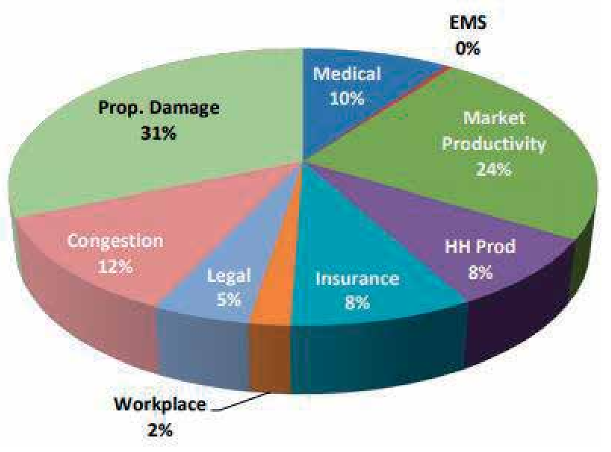


Figure 1.
Components of total economic costs.

driving, distractions to driver, red light jumping, and avoiding safety gears like seat belts and helmets [5]. A study prepared by the U.S. Department of Transportation's National Highway Traffic Safety Administration to be presented to the US Congress defines the causes of traffic accidents as driver-related, vehicle-related, roadway-related, and atmospheric condition-related factors [6].

From the view of a law firm in the United States, causes of accidents are long-listed as follows: distracted driving, speeding, drunk driving, reckless driving, rain, running red lights, running stop signs, teenage drivers, night driving, design defects, unsafe lane changes, wrong-way driving, improper turns, tailgating, driving under the influence of drugs, ice, snow, road rage, potholes, drowsy driving, tire blowouts, fog, deadly curves, animal crossings, and street racing [7]. Even though there seem to be many causes, it can be said that almost all of the accidents arise from the faults of humans. For instance, while drunk driving or running red lights are explicitly related to drivers, on the other hand, most of the vehicle- or road-related accidents such as tire blowouts (not changed in time) or unseen road signs (not controlled by road authority officials) are implicitly related to humans. This shows that humans must be in the center of the struggle for policies developed to prevent traffic accidents. Nevertheless, are the humans aware of that they are the main reasons for traffic accidents?

A recent study [8] researched the reasons behind the accidents by gathering data from the interview with police officers and drivers and also from traffic accident reports. Two of the main findings of the study are:

- The reasons for accidents differ between the genders and across the age groups.

- When police officers and drivers are asked to assign reasons to accidents, they only generated 25 possible causes; however, real accident reports included 63 accident causes [8].

The second finding mentioned above shows that the perceptions of people regarding accidents' causes are inadequate to understand the reasons and dynamics of accidents. Conversely, some factors such as uncorrected eyesight were listed by police officers and drivers; however, that did not take enough place in crash reports.

Traffic accidents cause inevitable and devastating individual, social, and economic impacts, and thus preventing those accidents is of great importance. So what can be done to solve this issue? The answer is quite simple: "What gets measured get managed" [9].

Since the end of the twentieth century, traffic accidents began to be analyzed by professionals in order to reveal the real underlying causes of traffic accidents. Projects like German In-Depth Accident Study (GIDAS) [10] are done to analyze and reconstruct traffic accidents. GIDAS project's objectives are the development of legislation, biomechanical research, automotive engineering arrangements, and public relations [11]. Similar studies are conducted all over the world; however, using scientific methods are far better than classical accident reporting methods. Because:

> *Underreporting due to inconsistent law enforcement practices may also explain why uncorrected or defective eyesight was frequently generated as a factor by police officers (and the public), but was rarely reported in the accident records. Policymakers rely on road accident statistics to inform their recommendations and new policy initiatives. Based on our current findings, we recommend that police officers and policymakers be cognizant of potential underreporting of factors associated with driver risk [8].*

Improving active and passive anti-collision systems, educating people, and conducting detailed (data) analyses are necessary in order to define policies. This kind of studies collect great amount of data for each accident [12], calculate several variables such as road friction coefficients [13], reconstruct accidents, and then evaluate several aspects of accidents such as injury probability functions for pedestrians and bicycles [14]. In addition to policymaking, improving vehicle safety, and educating people, there is another way to ensure safe roads: the use of smart technologies, in other words autonomous vehicles.

Artificial intelligence, one of the most popular phenomena of the last few years, is basically defined as "the capability of a machine to imitate intelligent human behavior" and "a branch of computer science dealing with the simulation of intelligent behavior in computers" [15]. Similarly, autonomous vehicles (AVs) are also expected to imitate human drivers' behaviors. Typically, in addition to a conventional vehicle, an AV has sensors to see its surrounding environment, complex CNN[1] or DNN[2] type (or similar) algorithms to analyze the data gathered, a powerful processor to make decisions, and other parts to convert the decisions to necessary actions.

Today, hundreds of thousands of AVs are on the roads. Besides, that number is anticipated to climb up, and autonomous cars are expected to constitute 25% of cars worldwide in 2035 [16]. However, what makes these AVs so unique? Is it the hi-tech equipment they have or the comfort they provide? Essentially, the prominent benefits they bring us are freedom of movement of incapables such as children or visually impaired people, better management of traffic flow, and the reduced number of accidents.

Nevertheless, some cannot trust in AVs and claim that AVs are not safe, at least 100% safe. Also, a recent research paper suggested that Level 2 and even Level 3 AVs would involve in accidents on German motorways [17]. But, are the AVs responsible for these accidents?

[1] Convolutional neural network (CNN): A specific type of artificial neural network that uses perceptrons and a machine learning unit algorithm, for supervised learning, to analyze data. CNNs apply to image processing, natural language processing, and other kinds of cognitive tasks.

[2] Deep neural network (DNN): A neural network with a certain level of complexity and a neural network with more than two layers. Deep neural networks use sophisticated mathematical modeling to process data in complex ways.

DMV (Department of Motor Vehicles) of California, shares the data of traffic accidents and according to related data, there are 234 accidents in which AVs are involved that happened in California from January 1, 2014 to December 31, 2019. However, this number does not mean that in all cases, the AVs are responsible [18]. In most cases, AVs are not the primary actors in these accidents, because they are equipped with several systems to prevent accidents such as lasers, high-powered cameras, radars, and even sonars. While they are not entirely safe, AVs are still in the developmental phase, and until Level 5 (fully automated, driverless) AVs set on roads, drivers will stay behind the wheels. Thus, people will be the main actor in traffic accidents. Due to the fact that 94% of the severe accidents stemmed from human errors [19], most policies and training programs must focus primarily on people.

Awareness creation, strict implementation of traffic rules, and scientific engineering measures are listed as methods for accident prevention in Ref. [20]. It is suggested that successful strategies for accident prevention must focus on six main areas that are national programs and target setting, safer driving behavior, safer vehicles and roads, safer pedestrians and vulnerable road users, education, training and publicity, and data systems (for analyses for policymakers) [21]. A detailed literature review of accidents that happened in the East and South Africa claims that related studies focused on four main fields: road safety policy, health education, safety equipment, and data collection.

As described so far, humans are the primary reasons for traffic accidents, and regardless of a driver's age, where he or she lives, or his or her country's developmental level, all policies shall put the humans in the center of their focus. Overall, setting high standards for licensure of drivers, strictly implementing traffic regulations, increasing public awareness, and promoting public transportations seem to be the best means in the field to prevent traffic accidents.

Author details

Murat Darçın* and Caner Filiz
Gendarmerie and Coast Guard Academy, Turkey

*Address all correspondence to: mrtdrc@yahoo.com

References

[1] Road Traffic Injuries [Internet]. 2020. Available from: https://www.who.int/en/news-room/fact-sheets/detail/road-traffic-injuries [cited: 01 February 2020]

[2] CDC Report Shows Motor Vehicle Crash Injuries Are Frequent and Costly [Internet]. 2014. Available from: https://www.cdc.gov/media/releases/2014/p1007-crash-injuries.html [cited: 02 February 2020]

[3] Blincoe LJ, Miller TR, Zaloshnja E, Lawrence BA. The economic and societal impact of motor vehicle crashes (report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration; 2015

[4] What Causes Traffic Accidents? [Internet]. Available from: https://www.koroad.or.kr/en_web/view/trfEnv4.do [cited: 05 February 2020]

[5] Causes of Road Accidents: Transport Department, Government of Jharkhand [Internet]. Available from: http://jhtransport.gov.in/causes-of-road-accidents.html [cited: 08 February 2020]

[6] National Motor Vehicle Crash Causation Survey (Report to Congress) [Internet]. 2008. Available from: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811059

[7] Top 25 Causes of Car Accidents [Internet]. Available from: https://seriousaccidents.com/legal-advice/top-causes-of-car-accidents/ [cited: 10 February 2020]

[8] Rolison JJ, Regev S, Moutari S, Feeney A. What are the factors that contribute to road accidents? An assessment of law enforcement views, ordinary drivers' opinions, and road accident records. Accident; Analysis and Prevention. 2018;**115**:11-24

[9] Prusak L. What Can't Be Measured. 2010. Available from: https://hbr.org/2010/10/what-cant-be-measured [cited: 12 February 2020]

[10] Methodology [Internet]. Available from: https://www.gidas.org/en/about-gidas/gidas-methodik/ [cited: 13 February 2020]

[11] GIDAS: German In-Depth Accident Study [Internet]. Available from: https://www.bast.de/BASt_2017/EN/Automotive_Engineering/Subjects/info-gidas.pdf?__blob=publicationFile&v=3 [cited: 13 February 2020]

[12] Data Collection [Internet]. Available from: https://www.vufo.de/en/forschung-und-entwicklung/datenerhebung/ [cited: 14 February 2020]

[13] Liers H, Spitzhuettl F. Injury Probability Functions for Pedestrians and Bicyclists Based on Real-World Accident Data [Internet]. 2017. Available from: https://trid.trb.org/view/1482493 [cited: 14 February 2020]

[14] Uhlenhof U. 5th International Conference on ESAR 2012. 5th International Conference on ESAR 2012 [Internet]. 2013. Available from: https://bast.opus.hbz-nrw.de/opus45-bast/frontdoor/index/index/docId/638 [cited: 14 February 2020]

[15] Artificial Intelligence [Internet]. Available from: https://www.merriam-webster.com/dictionary/artificialintelligence?utm_campaign=sd&utm_medium=serp&utm_source=jsonld [cited: 13 February 2020]

[16] Coren MJ. The Car Industry Is Heading Towards a Driverless Future [Internet]. Available from: https://www.weforum.org/agenda/2017/01/

having-a-baby-this-year-a-robotics-expert-thinks-theyll-never-drive-a-car/

[17] Unger T, Liers H. Prediction of the expected accident scenario of future Level 2 and Level 3 cars on German motorways. In: International Research Council on Biomechanics of Injury Conference (IRCOBI'19), Florence, Italy. 11-13 September 2019. pp. 47-57

[18] Wang S, Li Z. Exploring the Mechanism of Crashes with Automated Vehicles Using Statistical Modeling Approaches [Internet]. 2019. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6438496/ [cited: 14 February 2020]

[19] Automated Vehicles for Safety [Internet]. 2019. Available from: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety [cited: 14 February 2020]

[20] Gopalakrishnan S. A public health perspective of road traffic accidents. Journal of Family Medicine and Primary Care. 2012;**1**(2):144-150. DOI: 10.4103/2249-4863.104987

[21] A Guide for Policy Makers: On Reducing Road Fatalities [Internet]. PwC. Available from: https://www.pwc.com/m1/en/publications/guide-on-reducing-road-fatalities.html [cited: 14 February 2020]

Chapter 2

Attention Deficit Hyperactivity Disorder (ADHD) and Other Neurocognitive Factors Contributing to Road Traffic Accidents (RTA)

Thaddeus P. Ulzen

Abstract

Road traffic accidents (RTAs) are among the leading causes of mortality worldwide. RTAs are multifactorial in origin, but neurocognitive function of drivers contributes about 25% of the variance of most accidents. This chapter reviews the commonest disorders that contribute to RTA. They are attention deficit hyperactivity disorder (ADHD), specific learning disabilities (e.g., dyslexia), autism spectrum disorder (ASD) in adolescents and young adult drivers, and mild cognitive impairment (MCI) and dementia in older drivers. The features of these disorders and how they impair driving along with evidence-based treatments and interventions are discussed. Increasing awareness of these disorders, screening for them, and offering treatment when appropriate can contribute to reducing the disease burden related to RTA, which is currently the eighth leading cause of death across all ages globally. The lack of attention to these disorders within the road safety disciplines constitutes a significant public health problem which requires attention.

Keywords: neurocognitive factors, ADHD, learning disabilities (LD), dyslexia, autism spectrum disorder (ASD), mild cognitive impairment (MCI), dementia, road traffic accidents (RTAs)

1. Introduction

According to the World Health Organization (WHO), some 1.35 million people die and another 50 million people are injured or disabled from road traffic accidents (RTAs) annually across the globe. RTAs remain the eighth leading cause of death for people of all ages [1]. Unfortunately, the SDG target to halve road deaths by 2020 will not be achieved. The mortality rates in low-income countries are three times that of high-income countries. Though mortality from RTA has dropped by 50% over the last 16 years globally, the rate is far short of the SDG target. No low-income country has reduced its mortality rate from RTA since 2013. It is the leading cause of death between the ages of 5 and 29 years, globally [2].

While there are likely many factors contributing to these accidents in mortality and morbidity estimates, the relative contributions of individual driver neurocognitive characteristics are not fully understood or emphasized in road safety programs.

Neurocognitive difficulties resulting from conditions like attention deficit hyperactivity disorder (ADHD), specific learning disabilities, autism spectrum disorder and mild cognitive impairment, Alzheimer's disease, and other dementias, among other conditions, are likely to play a role in particular circumstances in road traffic accidents.

From a population health standpoint, these conditions have a fairly high prevalence among the driving public. The worldwide prevalence of ADHD is about 7%, Learning disabilities, such as dyslexia occur at about the rate of 7%, ASD at about 2% and dementia because it about 5–7% in most world regions in individuals over 60 years of age. In this chapter, a review of the current knowledge on the contribution of these individual driver factors to road traffic accidents is examined.

The WHO has developed road safety guidelines for member states, given the significant contributions of RTA to global disease burden. The pillars of focus are (1) road safety management, (2) safer roads and mobility, (3) safer vehicles, (4) safer road users, and (5) post-crash response. Interestingly, individual driver neurocognitive challenges are not directly addressed by this initiative. The WHO has focused on supporting member countries to enact legislation to manage excessive speeding, drunk driving, motorcycle helmet use, the use of seatbelts while driving, and child restraints, all of which are impacted by road user neurocognitive deficits. Compliance with these behavioral elements of road safety is affected by undiagnosed and untreated neurocognitive factors.

Since 2014, only 22% of member countries have amended their laws to fall in line with one or more of the key pillars, positively impacting about 14% of the world's population.

Driving is a complex cognitive-motor-perceptual-multi-tasking activity, and given the significant prevalence of disorders like ADHD, learning disabilities, ASD, and dementia, the core symptoms of these disorders are likely to contribute to road traffic accidents and are unlikely to be affected by the interventions outlined by the WHO. As a result, the standard of care requires physicians to notify their patients if their medical condition can potentially impair the operation of potentially dangerous equipment, such as motor vehicles. In fact, this is the law in most states [3]. Traditionally, neurocognitive functioning of drivers has not been considered a factor in evaluating road safety programs [2].

Individual driver factors reportedly comprise 25% of the variance of RTA [4].

In this chapter, the state of the literature in contributing to our understanding of the relationship between these disorders and driving is reviewed in the order below:

2. Attention deficit hyperactivity disorder (ADHD)

ADHD is one such individual-level factor, which has been extensively studied globally. Its core symptoms are inattention, distractibility, and impulsivity. It is mostly a genetic neurodevelopmental disorder beginning in childhood, which tends to be enduring and lifelong. Increasingly, emotional lability and difficulties with anger control have also been recognized as a common symptom [5, 6].

Other symptoms reflective of impaired executive functioning, including risk-taking behaviors such as difficulty in planning and setting priorities, make for an increased risk of accidents when someone with these symptoms is operating a motor vehicle. Evidence establishing driving risks has been obtained from self-report, informant report studies, simulation studies, on-road testing, and official driving records [7–9].

The literature over the past two decades suggest an association between ADHD and driving accidents in North America and other western countries [10, 11]. Barkley indicated that drivers themselves report inattention as the single most frequent reason for their car accidents [12]. Insurance data also suggests that ADHD drivers had 3.3 times more accident-related claims than controls [13]. Researchers have also presented findings suggesting that educational achievement is inversely related to road traffic driver accidents and injuries [14–16].

Identification of drivers with ADHD and their treatment has been correlated in some jurisdictions with reduced risk of RTAs and fatalities [14, 16–18]. Vaa in a meta-analysis in 2003 presented findings suggesting that individuals with ADHD had a 54% higher risk of being involved in an accident when compared with non-ADHD drivers [19]. However, in a later meta-analysis in 2014, Vaa et al. showed that comorbidity accounted for a large portion of the variability in ADHD-influenced accidents. They distinguished between intentional violations and driving errors. The former was more common in ADHD cormorbid with ODD and CD and the latter with ADHD occurring alone. Speeding was a common reason for driving errors in patients with ADHD alone [20]. This contradicted Barkley's 1993 finding of ADHD accounting for a fourfold increase in relation to RTA.

Chang et al., in a population-based prospective study in Norway, confirmed the increased risk of RTA in adults with ADHD and more importantly confirmed that with medication treatment, there was a 58% risk reduction for driving accidents in males [17]. There was no data on females reported in this study. Numerous studies have shown that treatment of ADHD with methylphenidate has been found to reduce collision and other traffic violation rates and also reduction in "angry and hectic driving" in drivers with ADHD [21–23].

Simulation studies have also addressed the comparative impairment caused by ADHD to that resulting from alcohol use in drivers. Subjects with ADHD had more difficulty maintaining constant speed than controls when tested with alcohol at 0.05% BAC relative to placebo. They also had a positive illusory bias which caused them to overestimate their abilities while driving and viewed themselves as less intoxicated than controls when tested with the same level of alcohol [24, 25]. These findings from simulation studies raise concerns about the additional risks posed by common comorbid conditions of ADHD, such as alcohol and substance abuse. It is established that individuals with untreated ADHD are more likely to have substance use disorders [26].

In an analysis of over 7000 severe pedestrian injuries and deaths, the New York City Department of Transportation in 2010, demonstrated the particular vulnerability of pedestrians in RTA. The results revealed that driver inattention accounted for 36% of the pedestrian-involved accidents. Drivers failing to yield to pedestrians, driver speed, and intoxication accounted for 27, 21, and 8%, respectively. Pedestrians were noted to be at fault in 20% of cases [1]. Importantly, most fatalities from accidents involve vulnerable populations like pedestrians, cyclists, and motorbike riders [1]. Inattention is a core ADHD symptom, and speeding was often a reflection of impulsivity, another core ADHD symptom. Additionally, drivers with ADHD seem to have more distractibility during low-stimulus driving such as found on interstate highways. They tend to be more fatigue-prone in these situations, from visual and task monitoring [27].

Individuals with ADHD are at significant risk of being involved in RTA due to the features of their condition. This reality is supported by many studies showing increased rates of motor vehicle accidents and impulsive-influenced driving behaviors compared with those without ADHD. Both pharmacologic and non-pharmacologic interventions can reduce these risks. The non-pharmacologic interventions include manual transmission vehicles, hazard perception training, and electronic motion alerts on vehicles [28, 29].

Treating physicians should consider the potential impact of a patient's ADHD symptoms on driving behaviors and possible related outcomes when developing a treatment plan for their patients. Significant psychoeducation is central to a positive outcome, resulting in improved treatment compliance.

3. Specific learning disabilities

Specific learning disabilities are also a source difficulty in driving for those afflicted. They are often comorbid with ADHD in about 30% of individuals with either disorder. Dyslexia is the commonest of the specific learning disabilities. It has been estimated that 7% of the population could be considered as dyslexic, a specific learning disorder impairing accurate or fluent word recognition despite adequate instruction and intelligence and intact sensory abilities [30].

Individuals with dyslexia have difficulty perceiving written words accurately in their environment. There are numerous kinds of dyslexia, including phonological dyslexia, which includes selective difficulty with nonword reading; surface dyslexia, which is selective difficulty with exception of word reading, and visual dyslexia, where words are frequently misread as another, particularly visually similar words. There is also lexical non-semantic reading, i.e., reading without comprehension and pure alexia where words can only be read letter by letter.

This suggests that the reading of road signs, for example, can be quite problematic for these individuals. Moving text messages that are now more frequently used as road signs would be more difficult for them.

They have shorter legibility distances because they have to make a greater cognitive effort to accurately decipher road signs. While trying to read road signs when driving, there is more gazing and poor speed control. They have a longer reading time and have to apply an increased cognitive effort.

These drivers are usually helped by the use of pictograms rather than written words or moving text messages that have become more popular. The use of pictograms in conjunction with the written word is helpful in reducing accidents in this population. Dyslexia is traditionally considered as a language-based disorder, and consequently, the processing of pictorial information would be theoretically preserved [30].

Other controlled studies show that even with pictorial signs, individuals with dyslexia are slower to decipher what they see [31]. Sigmundsson 2005 showed that dyslexic individuals had significantly slower responses than controls to signs shown to them in a simulator-based experiment [32].

Roca et al. confirmed this finding and suggest that pictorial information could be a potential countermeasure to reduce driving risk for dyslexic drivers but also cautioned that reliance on pictograms must be considered with care, because it was observed in their study that participants with dyslexia also showed increased cognitive effort when trying to identify the pictograms in the variable message signs (VMS) [33].

This is an area in which further research will be useful in clarifying the extent to which the processing of pictogram-based information can be more demanding for adult drivers with dyslexia than non-dyslexic control participants.

Specific learning disorders like dyslexia are often overlooked as deficits that are relevant in road safety because by definition, those afflicted have normal or superior cognitive and intellectual abilities. They have no outward signs of deficits.

4. Autism spectrum disorder

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition, which is associated with impairment of communication and social interaction, along with executive function deficits affecting working memory, motor coordination, attention, planning, mental flexibility, and visual perception [34, 35]. It has a worldwide prevalence of 0.6–2% [36] and is often comorbid with ADHD. They have great difficulty obtaining driver's licenses. When they do obtain licenses, they do so much later than their neurotypical counterparts. In most countries, gaining a driver's license represents increased independence and can lead to improved quality of life for individuals and their families [37].

A recent literature review by Lindsay [38] indicated that youth with ASD have face difficulties in obtaining a driver's license. They have difficulty with handling unexpected changes, sustaining attention for long drives, and merging into traffic and limited ability in reading facial expressions and gestures of other drivers. They also have issues with anxiety which manifest as poor driver confidence due to lower reaction time in changing situations. As a result, they avoid heavy traffic or highways or driving at night and have problems adhering to speed regulations and staying in their lanes.

These result in poor driving performance. They have an increased risk of accidents and have more driving hazards because they tend to delay in responding to social hazards requiring interaction with other road users. They are slow in perceiving and responding to social stimuli within the driving context [39]. Research shows that people on the autism spectrum are also at greater risk of being involved in motor vehicle accidents, which poses risks not only for them but also for other road users in the community [40].

They have atypical eye gaze patterns, e.g., they may be fixated on billboards or their speedometer when they are driving. They tend to have increased anxiety if other drivers deviate from road rules, and they focus on those events instead of managing their own vehicles.

They tend to have increased reaction times to changes in the driving environment and more tactical driving difficulties with more crashes, as they have poor situational awareness [41].

They require specific interventions to make them safer drivers. Useful strategies for teaching people with ASD to drive include direct communication, minimal verbal correction, encouraging coping mechanisms, breaking down tasks into smaller segments, and providing regular and consistent short-duration driving lessons. In many jurisdictions, there is an opportunity for clinicians and educators to advocate for further transportation-related training and supports for people with ASD [38]. They also require regular and consistent driving lessons over a longer period of time to achieve the level of skill required to acquire a license.

Many countries currently have no autism-specific licensing requirements for learner drivers, and there is a general lack of ASD-specific support and training packages for individuals, their families, and driving instructors [39]. At a minimum, it is important to identify treatable comorbid conditions like ADHD and anxiety in these individuals to assist in making them safer drivers.

5. Mild cognitive impairment and dementia

It is estimated (2016) that there are 5.4 million individuals in the United States with dementia. It is projected that by 2050 there will be 13.8 million people with dementia in the United States [42]. There is a public health concern that many with mild cognitive impairment and dementia continue to drive, in spite of the deficits associated with these conditions. These include memory impairment, poor decision-making, poor problem-solving skills, impaired insight and judgment, difficulties with hand-eye coordination, reduced reaction time, visual attention deficits, and decreased visual spatial abilities [43]. Clinicians are often wary of advising these patients to stop driving because of the negative impact this will have on their autonomy and on the doctor-patient relationship [44]. These concerns contribute to under-reporting of patients to the appropriate transportation authorities in jurisdictions with mandatory reporting requirements [45].

Recent cross-sectional study on women's health revealed at 60% of older women with a mean age of 84 years with mild cognitive impairment and 40% with dementia were still driving at the time of assessment [46].

Hird et al. [47] reported that patients with very mild Alzheimer's disease (CDR-0.5) and mild Alzheimer's disease (CDR-1.0) were more likely to fail on-road tests than healthy control drivers (CDR-0.0) with failure rates of 13.6, 33.3, and 1.6%, respectively.

Chee et al. [48] reported that there is still a great deal of work to be done in determining the absolute and relative risk of motor vehicle collisions or driving impairment in patients with mild cognitive impairment and Alzheimer's disease.

Screening instruments that are currently used to evaluate cognitive functioning are unable to distinguish between patients who should be referred to specialized driving centers for assessment. It is also difficult to accurately assess recommendations on caregiver's opinion of driving performance and fitness to drive in the elderly [49].

More on-road assessment studies in older adults with dementia are needed to enhance confidence in on-road assessment prediction to find common ground to define the severity of dementia.

Motor vehicle collision data may play a more important role in mild cognitive impairment and preclinical dementia, as these diagnoses become more commonplace among the elderly who continue to drive. A clinically useful evidence-based algorithm for predicting safe driving among patients with mild stages of dementia remains elusive [50, 51].

Clinically, driving behaviors such as problems identifying landmarks or signs, lost trips, not wearing a seatbelt, less freeway driving, and closer to home and daylight driving may all be red flags suggesting that an elderly person may have worsening cognitive function and probably should not be driving. Additionally, assessment of activities of daily living (ADLs) may be a predictor of one's ability to drive based on a broader assessment of functional capacity [52].

At earlier stages of cognitive decline, drivers are often less familiar with their personal limitations and may take more risks. Earlier assessment and interventions with driving ability have a greater potential to improve driving safety more effectively or, alternately, offer guidance on the timeliness of decisions regarding driving cessation, which are often difficult for healthcare providers, patients, and families alike.

There may also be a role for technology, e.g., instrumented vehicles, GPS tracking, and other data sensors which may provide interesting solutions to carefully study the longitudinal deterioration in driving ability of patients with dementia [53–55].

6. Summary

This review of common neurocognitive disorders that have an impact on driving raises questions about the application of the current state of knowledge to rules, regulations, and laws governing the operation of motor vehicles in most jurisdictions.

The paradox is that in many jurisdictions applicants for drivers' licenses have to declare whether they have epilepsy, which has a worldwide prevalence of 0.6% [56].

The disorders discussed in this chapter are much more prevalent and together are greater source of danger for drivers, both private and commercial and other road users.

Attention deficit hyperactivity disorder (ADHD), learning disabilities (LD), autism spectrum disorder (ASD), and dementia are all conditions for which simple validated screening tools are available. There is therefore a need to create capacity and knowledge within licensing and regulatory agencies, in collaboration with mental health professionals to ensure that individuals diagnosed with treatable conditions receive treatment for their own well-being and also for the safety of the public.

These conditions together with others that may not have been covered in this chapter constitute a significant public health concern and need to be addressed holistically within most jurisdictions to improve the safety of the driving public and pedestrians as well.

Author details

Thaddeus P. Ulzen
Department of Psychiatry and Behavioral Medicine, College of Community Health Sciences, The University of Alabama and University of Alabama School of Medicine (Tuscaloosa Regional Campus), The University of Alabama, Tuscaloosa, AL, USA

*Address all correspondence to: tulzen@ua.edu

References

[1] World Health Organization. Disease, Injury and Causes of Death Country Estimates, 2000-20151 [Internet]. World Health Organization; 2017. Available from: http://www.who.int/healthinfo/global_burden_disease/estimates_country_2000_2015/en/

[2] WHO: Global Status Report on Road Safety. 2018

[3] Code of Virginia. Title 54.1 Professions and Occupations—Section 54.1-2966.1 Physicians reporting disabilities of drivers. Vol 1988, c. 798, section 54-276.9:2

[4] Treat JR et al. Tri-level Study of the Causes of Traffic Accidents. Causal Factor Tabulations and Assessment. Vol. I. Washington, DC: U.S. Department of Transportation (Publication Number DOT-HS-805-085); 2007

[5] Richards T, Deffenbacher J, Rosen L. Driving anger and other driving-related behaviors in high and low ADHD symptom college students. Journal of Attention Disorders. 2002;**6**:25-38

[6] Skirrow C, Asherson P. Emotional lability, comorbidity and impairment in adults with attention-deficit hyperactivity disorder. Journal of Affective Disorders. 2013;**147**(1-3):80-86

[7] Aduen PA, Kofler MJ, Cox DJ, Sarver DE, Lunsford E. Motor vehicle driving in high incidence psychiatric disability: Comparison of drivers with ADHD, depression, and no known psychopathology. Journal of Psychiatric Research. 2015;**64**:59-66

[8] Narad M, Garner AA, Brassell AA, Saxby D, Antonini TN, O'Brien KM. Adolescents with ADHD demonstrate driving inconsistency. Impact of distraction on the driving performance of adolescents with and without attention-deficit/hyperactivity disorder. JAMA Pediatrics. 2013;**167**:933-938

[9] Merkel RLJ, Nichols JQ, Fellers JC, Hidalgo P, Martinez LA, Putziger I, et al. Comparison of on-road driving between young adults with and without ADHD. Journal of Attention Disorders. 2016;**20**(3):260-269. DOI: 10.1177/1087054712473832

[10] Cox DJ et al. Self-reported incidences of moving vehicle collisions and citations among drivers with ADHD: A cross-sectional survey across the lifespan. American Journal of Psychiatry. 2011;**168**(3):329-330

[11] Jerome L et al. What we know about ADHD and driving risk: A literature review, meta-analysis and critique. Journal of the Canadian Academy of Child and Adolescent Psychiatry. 2006;**15**(3):105-125

[12] Barkley RA. Major life activity and health outcomes associated with attention deficit/hyperactivity disorder. Journal of Clinical Psychiatry. 2002;**63**(12 suppl):10-15

[13] Swensen A, Birnbaum HG, Ben Hamadi R, et al. Incidence and costs of accidents among attention-deficit/hyperactivity disorder patients. The Journal of Adolescent Health. 2004;**35**(346):e1-e9

[14] Barkley RA, Cox D. A review of driving risks and impairments associated with attention-deficit/hyperactivity disorder and the effects of stimulant medication on driving performance. Journal of Safety Research. 2007;**38**(1):113-128

[15] Hasselberg M, Laflamme L. Socioeconomic background and road traffic injuries: A study of young

car drivers in Sweden. Traffic Injury Prevention. 2003;**4**(3):249-254

[16] Lam LT. Distractions and the risk of car crash injury: The effect of drivers' age. Journal of Safety Research. 2002;**33**(3):411-419

[17] Chang Z et al. Serious transport accidents in adults with attention-deficit/hyperactivity disorder and the effect of medication: A population-based study. Journal of the American of Medical Association, JAMA Psychiatry. 2014;**71**(3):319-325

[18] Jerome L. The benefit of stimulants in reducing driving risk in adult drivers with ADHD. CMAJ: Canadian Medical Association Journal. 2014;**186**(9):698

[19] Vaa T. Impairments, Diseases, Age and their Relative Risks of Accident Involvement: Results from Meta-Analysis. Oslo, Norway: Institute of Transport Economics; 2003

[20] Vaa T. ADHD and relative risk of accidents in road traffic: A meta-analysis. Accident Analysis & Prevention. 2014;**62**:415-425

[21] Sobanski E, Sablijic D, Alm B, et al. Driving-related risks and impact of methylphenidate treatment on driving in adults with attention-deficit/hyperactivity disorder (ADHD). Journal of Neural Transmission. 2008;**115**:347-356

[22] Verster JC, Bekker EM, de Roos M, et al. Methylphenidate significantly improves driving performance of adults with attention-deficit hyperactivity disorder: A randomized crossover trial. Journal of Psychopharmacology. 2008;**22**:230-237

[23] Cox DJ, Davis M, Mikami AY, Singh H, Merkel RL, Burket R. Long-acting methylphenidate reduces collision rates of young adult drivers with attention-deficit/hyperactivity disorder. Journal of Clinical Psychopharmacology. 2012;**32**:225-230

[24] Diener MB, Milich R. Effects of positive feedback on the social interactions of boys with attention deficit hyperactivity disorder: A test of the self-protective hypothesis. Journal of Clinical Child Psychology. 1997;**26**(3):256-265

[25] Weafer J. Simulated driving performance of adults with ADHD: Comparisons with alcohol intoxication. Experimental and Clinical Psychopharmacology. 2008;**16**(3):251-263

[26] Wilens TE. The nature of the relationship between attention-deficit/hyperactivity disorder and substance use. Journal of Clinical Psychiatry. 2007;**68**(suppl 11):4-8

[27] Reimer B, D'Ambrosio LA, Coughlin JF, Fried R, Biederman J. Task-induced fatigue and collisions in adult drivers with attention deficit hyperactivity disorder. Traffic Injury Prevention. 2007;**8**:290-299

[28] Cox DJ, Punja M, Powers K, et al. Manual transmission enhance attention and driving performance of ADHD adolescent males: Pilot study. Journal of Attention Disorders. 2006;**10**:212-226

[29] Poulsen AA, Horswill MS, Wetton MA, Hill A, Lim SM. A brief office-based hazard perception intervention for drivers with ADHD symptoms. The Australian and New Zealand Journal of Psychiatry. 2010;**44**:528-534

[30] Peterson RL, Pennington BF. Developmental dyslexia. Lancet. 2012;**379**(9830):1997-2007

[31] Taylor B, Chekaluk E, Irwin J. Reading the situation: The relationship

between dyslexia and situational awareness for road sign information. Transportation Research Part F: Traffic Psychology and Behaviour. 2016;**36**:6-13

[32] Sigmundsson H. Do visual processing deficits cause problem on response time task for dyslexics? Brain and Cognition. 2005;**58**(2):213-216

[33] Roca J, Tejero P, Insa B. Accident ahead? Difficulties of drivers with and without reading impairment recognising words and pictograms in variable message signs. Applied Ergonomics. 2018;**67**:83-90

[34] Brooks J, Kellett J, Seeanner J, et al. Training the motor aspects of pre-driving skills of young adults with and without autism spectrum disorder. Journal of Autism and Developmental Disorders. 2016;**46**(7):2408-2426

[35] Cox SM, Cox DJ, Kofler MJ, et al. Driving simulator performance in novice drivers with autism spectrum disorder: The role of executive functions and basic motor skills. Journal of Autism and Developmental Disorders. 2016;**46**(4):1379-1391

[36] Elsabbagh M, Divan G, Koh Y, Kim YS, Kauchali S, Marcín C, et al. Global epidemiology of autism. Autism Research. 2012;**5**:160-179

[37] Almberg M, Selander H, Falkmer M, Vaz S, Ciccarelli M, Falkmer T. Experiences of facilitators or barriers in driving education from learner and novice drivers with ADHD or ASD and their driving instructors. Developmental Neurorehabilitation. 2017;**20**(2):59-67

[38] Lindsay S. Systematic review of factors affecting driving and motor vehicle transportation among people with autism spectrum disorder. Disability and Rehabilitation. 2017;**39**(9):837-846

[39] Tyler S. Asperger's syndrome: The implications for driver training methods and road safety. Journal of the Australasian College of Road Safety. 2013;**24**(1):55-63

[40] Classen S, Monahan M. Evidence-based review on interventions and determinants of driving performance in teens with attention deficit hyperactivity disorder or autism spectrum disorder. Traffic Injury Prevention. 2013;**14**(2):188-193

[41] Silvi C, Scott-Parker B, Jones C. A literature review of the likely effects of autism spectrum disorder on adolescent driving abilities. In: Adolescent Research Review. USA: Springer Publishing; 2017. pp. 1-17

[42] Alzheimer's Association. 2016 Alzheimer's disease facts and figures. Alzheimer's & Dementia. 2016;**12**:459-509

[43] Uc EY, Rizzo M, Anderson SW, et al. Driver landmark and traffic sign identification in early Alzheimer's disease. Journal of Neurology, Neurosurgery, and Psychiatry. 2005;**76**:764-768

[44] Jang RW, Man-Son-Hing M, Molnar FJ, et al. Family physicians' attitudes and practices regarding assessments of medical fitness to drive in older persons. Journal of General Internal Medicine. 2007;**22**:531-543

[45] Pimlott NJ, Siegel K, Persaud M, et al. Management of dementia by family physicians in academic settings. Canadian Family Physician. 2006;**52**:1108-1109

[46] Vaughan L, Hogan PE, Rapp SR, et al. Driving with mild cognitive impairment or dementia: Cognitive test performance and proxy report of daily life function in older women. Journal of the American Geriatrics Society. 2015;**63**:1774-1782

[47] Hird MA, Egeto P, Fischer CE, et al. A systematic review and meta-analysis of on-road simulator and cognitive driving assessment in Alzheimer's disease and mild cognitive impairment. Journal of Alzheimer's Disease. 2016;**53**:713-729

[48] Chee J, Rapoport M, Molnar F, et al. American Journal of Geriatric Psychiatry. 2017;**25**(12):1376-1390

[49] Man-Son-Hing M, Marshall SC, Molnar FJ, et al. Systematic review of driving risk and the efficacy of compensatory strategies in persons with dementia. Journal of the American Geriatrics Society. 2007;**55**:878-884

[50] Bennett JM, Chekaluk E, Batchelor J. Cognitive tests and determining fitness to drive in dementia: A systematic review. Journal of the American Geriatrics Society. 2016;**64**:1904-1917

[51] Molnar FJ, Patel A, Marshall SC, et al. Clinical utility of office-based cognitive predictors of fitness to drive in persons with dementia: A systematic review. Journal of the American Geriatrics Society. 2006;**54**:1809-1824

[52] Cornelis E, Gorus E, Beyer I, et al. Early diagnosis of mild cognitive impairment and mild dementia through basic and instrumental activities of daily living: Development of a new evaluation tool. PLoS Medicine. 2017;**14**:e1002250

[53] Marshall SC, Man-Son-Hing M, Charlton J, et al. The Candrive/Ozcandrive prospective older driver study: Methodology and early study findings. Accident; Analysis and Prevention. 2013;**61**:233-235

[54] Dawson JD, Anderson SW, Uc EY, et al. Predictors of driving safety in early Alzheimer disease. Neurology. 2009;**72**:521-527

[55] Eby DW, Silverstein NM, Molnar LJ, et al. Driving behaviors in early stage dementia: A study using in-vehicle technology. Accident; Analysis and Prevention. 2012;**49**:330-337

[56] Fiest KM, Sauro KM, Wiebe S, et al. Prevalence and incidence of epilepsy: A systematic review and meta-analysis of international studies [published correction appears in Neurology. 2017 Aug 8;89(6):642]. Neurology. 2017;**88**(3):296-303. DOI: 10.1212/WNL.0000000000003509

Chapter 3

Can Autonomous Vehicles Prevent Traffic Accidents?

Caner Filiz

Abstract

Today, thousands of autonomous vehicles (AVs), also known as self-driving cars, are on roads. Besides, that number is anticipated to climb up, and AVs are expected to constitute 25% of cars worldwide in 2035. However, can AVs prevent traffic accidents? Results show that use of AVs will stay as a concern, and it will be hard to either champion or oppose them. From a positive perspective, AVs will contribute to traffic safety, increase economic and social benefits, and contribute to environmental protection. However, from a negative point of view, AVs would be hacked, expose our data to third parties, cause liability problems, increase carbon emissions into the atmosphere, risk our health, and constitute a financial burden in economies. The first section will introduce this chapter. The second section will give general information on the history AVs with a general description of them. How AVs work will be explained in the third section. The fourth section will mention the concerns regarding AVs. The pros, cons, and moral issues of AVs will be shown in the fifth section. The sixth chapter will argue the legal issues regarding AVs. Then, the seventh and final section will provide a conclusion.

Keywords: artificial intelligence (AI), autonomous vehicle (AV), self-driving car, computer vision, traffic accident, accident prevention

1. Introduction

Each year approximately 1.35 million people die as a result of traffic accidents that also cost most countries millions of dollars [1]. However, this unfortunate phenomenon mostly stems from humans. According to the US Department of Transportation's National Highway Traffic Safety Administration (NHTSA), 94% of the severe traffic accidents happen because of human errors [2].

Korean Road Traffic Authority defines the causes of traffic accidents as unsafe factors, unsafe road environments, insufficient driver knowledge, failure to recognize the danger, and improper thinking [3]. A study prepared by the NHTSA to be presented to the US Congress defines the causes of traffic accidents as driver-related, vehicle-related, roadway-related, and atmospheric condition-related factors [4].

Law firms approach problems from a different point of view since they aim to defend people at courts. As a result, they list the reasons for accidents in accordance with their legal bases. From the view of a law firm in the USA, causes of accidents are long listed as follows: distracted driving, speeding, drunk driving, reckless driving, rain, running red lights, running stop signs, teenage drivers, night driving, design defects, unsafe lane changes, wrong-way driving, improper turns, tailgating, driving under the influence of drugs, ice, snow, road rage, potholes, drowsy driving, tire blowouts, fog, deadly curves, animal crossings, and street racing [5].

Some may suggest that tire blowouts or unseen road signs are not human-related. However, while drunk driving or running red lights are explicitly related to drivers, a tire that is not changed in time or an unseen road sign that is not controlled by road authority employee is still implicitly associated with humans and human errors. Overall, it can be said that almost all accidents arise from the faults of humans, as suggested by NHTSA [2]. Nevertheless, are the humans aware that they are the main reasons for traffic accidents?

A recent study [6] researched the reasons behind the accidents by gathering data from the interview with police officers and drivers and traffic accident reports. Two of the main findings of the study are as follows:

- the reasons for accidents differ between the genders and across the age groups and

- when police officers and drivers are asked to assign the reasons for accidents, they only generated 25 possible causes; however, real accident reports included 63 accident causes [6].

The second finding mentioned above shows that the perceptions of people regarding accidents' causes are inadequate to understand the reasons and dynamics of accidents. Conversely, some factors such as uncorrected eyesight were listed by police officers and drivers; however, that did not take enough place in crash reports. While even police officers may have difficulty in identifying reasons behind accidents, how can we expect humans to take necessary actions to prevent traffic accidents? Or from another point of view, can AVs perform better than humans in driving? Before digging into details, first, we must look at the basic definition and the history of AVs.

2. The basic definition and a brief history of AVs

2.1 The basic definition of AV

AVs can be defined as the (self-driving) cars and trucks that combine sensors and software to control the vehicle safely without human drivers [7]. This definition mostly defines **fully** autonomous vehicles, which are not present now. However, there is a generally accepted road map and classification for autonomous cars prepared by the Society of Automotive Engineers (SAE) that will take humanity to a fully autonomous cars' era. The classification consists of six categories to define the developmental level of autonomous vehicles ranging from Level 0 to Level 5 [8]. **Figure 1** presents these classifications below.

2.2 The brief history of AVs

It is hard to find a starting point for the evolution of AVs. Encyclopedia Britannica suggests that AVs have taken place in science fiction works written by authors such as Isaac Asimov and Ray Bradbury [9]. It is also claimed that the time of the emergence of AVs on earth is the 1920s, and radio- or wire-controlled cars are examples of them. Isaac Asimov's short story "Sally" features autonomous cars that contain positronic brains and do not require human drivers [10]. The cars in this sci-fi example satisfy the basic definition provided in this section; however, it is hard to say that radio- or wire-controlled cars are the prototypes or precedents of

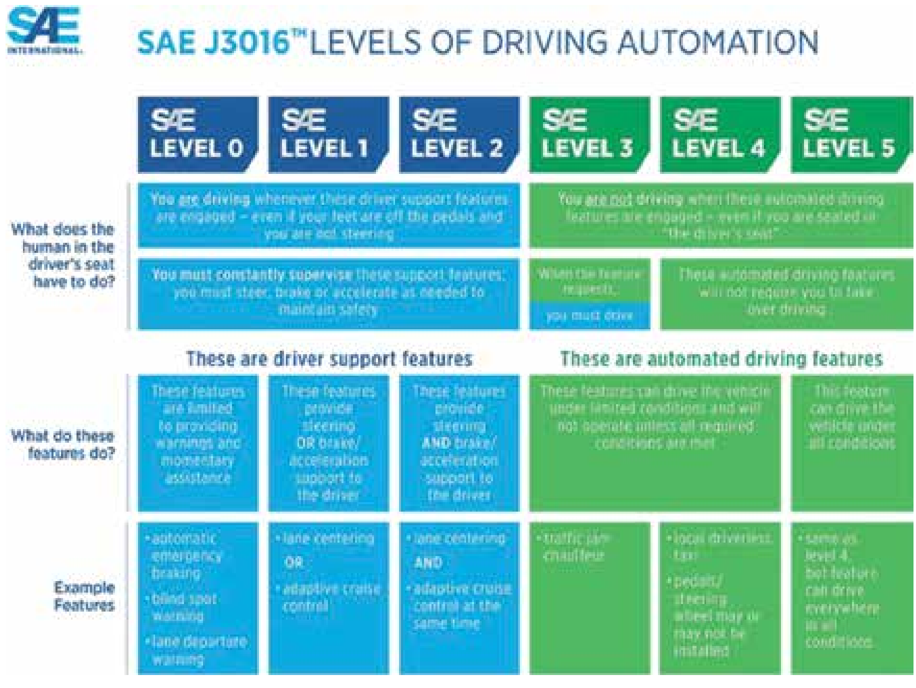


Figure 1.
Levels of autonomy (courtesy of SAE international).

today's AVs because they are directly controlled by humans, and this situation does not comply with the definition.

Modern (and capable) AVs can be said to show up through the challenges that were held by the United States (US) Defense Advanced Research Projects Agency (DARPA). In 2004, DARPA launched its first grand challenge to speed up the invention of the first fully autonomous ground vehicles. On the first grand challenge, 15 participant teams were asked to send their AVs from Barstow, California to Primm, Nevada (a 142-mile course in dessert terrain) on March 13, 2004 [11]. However, none of the AVs completed the route, and Carnegie Mellon University's Red Team's AV "Sandstorm" was the car that took the farthest distance, only 7.4 miles. Hence, the prize of $1 million went to none of the participants [12].

Eighteen months later, DARPA held its second grand challenge in the fall of 2005 with a prize of $2 million. At this challenge, 5 AVs of 195 were able to complete a 132-mile route in southern Nevada. Stanford University's AV "Stanley" won the challenge with a time of 6 hours and 53 minutes [13].

This second grand challenge proved that it is possible to make an AV that can drive itself in a demanding territory. The next step was to have AVs that can operate on the streets of a city. In 2007, DARPA conducted its third challenge under the name of "Urban Challenge." This time, AVs are asked to drive through the streets of Victorville, California on November 1, 2007, and Tartan Racing's Boss completed the race and won the prize of $2 million [14].

Besides the places they took, there were two factors that made Urban Challenge different from the previous two Grand Challenges. Urban Challenge required the participating teams to satisfy two primary necessities. The first one was to follow the California driving rules, and the second one was to succeed in the National Qualification Event (NQE) [14].

It was apparent that the participants were supposed to follow the traffic rules. Besides, it was also noteworthy that referees gave extra points to AVs if they followed the rules. For instance, though Stanford University's "Junior" completed the route 1 minute earlier than Tartan Racing's "Boss"; however, the latter was announced as the winner since it earned extra points for obeying the traffic rules [14].

Another important part of the necessities to be satisfied was the NQE. Consisting of three parts, NQE was held before the Urban Challenge to be sure that AVs were safe enough to self-drive through the streets of Victorville. The first part of the NQE, NQE A, required AVs to merge into and out of two-way jammed traffic. NQE B tested the AVs' ability to stay within a lane in an environment with obstacles and finally find an assigned place for parking. During NQE C, AVs were tested for their abilities of intersection behaviors, U-turn, and road re-planning. As a result of overall NQE, 11 of 35 AVs were selected to attend Urban Challenge [14]. It can be said that setting requirements such as following traffic rules and satisfying NQE are the milestones for AV regulations today.

3. How AVs work

An AV uses several systems to replace a human driver and drive itself. Analogous to human body, a digital brain is necessary to manage all processes needed to drive a car. Gathering data from several sources such as radio detection and ranging (RADAR),[1] sound navigation and ranging (SONAR),[2] light detection and ranging (LIDAR)[3] devices and cameras; employing computer vision to gather data and then processing those data; sending commands to mechanical parts to move AV such as making turns or stopping, and doing all these itself require an advanced computer program. Self-learning and self-acting capabilities cause these programs to be named as artificial intelligence (AI). So, what is AI?

AI, one of the most popular phenomena of the last few years, is defined as "a branch of computer science dealing with the simulation of intelligent behavior in computers" and "the capability of a machine to imitate intelligent human behavior" [15]. Similarly, as intelligent agents, AVs are also expected to imitate human drivers' behaviors. Typically, in addition to a conventional vehicle, an AV has sensors to see its surrounding environment, complex CNN[4] or DNN[5] type (or similar) algorithms to analyze the data gathered, a powerful processor to make decisions, and other parts to convert the decisions to necessary actions.

While working, an AV senses and sees every detail around itself. A traffic sign, a pedestrian on a sidewalk, a traffic light, other cars passing by, buildings surrounding horizon, and even a street animal jumping into the road must be analyzed with the AI of AV to prevent any unwanted consequences.

---

[1] RADAR is a device or system consisting usually of a synchronized radio transmitter and receiver that emits radio waves and processes their reflections for display and is used especially for detecting and locating objects (such as aircraft) or surface features (as of a planet).

[2] SONAR is a method or device for detecting and locating objects especially underwater by means of sound waves sent out to be reflected by the objects.

[3] LIDAR is a device that is similar in operation to radar but emits pulsed laser light instead of microwaves.

[4] Convolutional Neural Network (CNN): a specific type of artificial neural network that uses perceptrons, a machine learning unit algorithm, for supervised learning, to analyze data. CNNs apply to image processing, natural language processing, and other kinds of cognitive tasks.

[5] Deep Neural Network (DNN): a neural network with a certain level of complexity and a neural network with more than two layers. Deep neural networks use sophisticated mathematical modeling to process data in complex ways.

The second main part of an AV is its sensors. These sensors, as mentioned above, include mostly radars, lidars, sonars, and cameras. A radar is a device that transmits radio signals, receives them back and calculate the differences between those signals to detect objects, their sizes, velocities, and distances. Depending on its purpose and the platform it is used, a radar uses the signals at different wavelengths. A sonar works in the same manner; however, it employs sound waves (a specific subset of radio waves). A lidar, on the other hand, sends and receives millions of light beams. These systems have comparative advantages and disadvantages over each other, and AVs use them together to close any safety gap.

In terms of range, radar has the advantage over lidar, sonar, and camera. Because lidar and camera require visibility all times, sonar has a shorter working range. On the other hand, since an AV is mostly interested in its close circumference, lidar is the most advantageous one because of its speed and high frequency-high quality data gathering capability [16]. Cameras are better in image gathering, and sonars are better in close range object detection.

4. Are AVs really safe?

When it comes to reliability, all of four common sensors of AVs have security deficiencies, for example, radars and sonars could be jammed with electromagnetic waves. When these two transmit the signals, someone can use an energy source emitting (reflecting) waves in the same wavelength from a different range or a different angle. When it comes to lidar, special devices can be used to create light noise to jam lidar. The exciting part is related to cameras. The AIs of AVs use camera data for image detection and recognition with high accuracy; however, a recent study proved that simple physical elements or invisible attack patterns could be used to mislead AIs [17].

Figure 2 shows a specific example to attack by using physical elements. In this figure, a regular stop sign was attached with some black and white tapes. While these taped patterns do not create suspicion in humans, it may cause severe consequences for AVs because this stop sign in **Figure 2** is received by a CNN algorithm as a “Speed Limit 45” sign as in **Figure 3** with a probability of up to 100% [18].

Another issue regarding the safety of AVs is the possibility of being hacked. In a controlled experiment conducted in earlier July 2015, two security researchers took over the control of a Jeep Cherokee [19]. The SUV was not an AV; however, it

Figure 2.
A stop sign with camouflage art attack (reproduced based on figures in Table 1 of [18]).

Figure 3.
*How the stop sign in **Figure 2** is seen by AV (courtesy of https://freesvg.org/).*

connected to the internet via an interface named Uconnect that was used in thousands of automobiles. The researchers hacked the Uconnect and conducted several actions such as blowing music out from speakers, killing the engine while running, disengaging the brakes, and finally pulling over the car. Upon this incident, Fiat Chrysler Automobiles recalled 1.4 million vehicles to solve the vulnerability issues of Uconnect [20].

All these threats are considered seriously by governments, universities, researchers, and AV manufacturers. Also, as said in the third section, several different types of sensors are combined to assure safety. For instance, NHTSA follows a comprehensive and systematic approach to develop layered security and conducts research activities such as anomaly based intrusion detection or cybersecurity for update mechanisms of firmware [21].

5. The pros, cons, and moral issues of AVs

AVs are on the roads today, and they will unavoidably be a part of our lives. So, what are the pros of AVs? In other words, how can we benefit from them? Or, what are their cons; if there exist, what are the risks or dangers they will bring to our lives? There is an ongoing debate on this topic, and this section will try to clarify these questions.

5.1 The pros of AVs

5.1.1 Safety

NHTSA conducted a study for crash causation and examined accidents that occurred between July 3, 2005, and December 31, 2006 [4]. According to the study, 40.6% of the 5096 accidents were related to recognition errors such as inadequate surveillance and internal/external distraction. About 34.1% of accidents were related to decision errors such as misjudgment of other's speed, driving too fast for conditions, and false assumption of other's action; and 10.3% of accidents were related to performance errors such as panics. While using AI, supported by several sensors, it might be claimed that AVs are less prone-to-errors than humans.

Another issue with traffic accidents is the driver's general or momentary consciousness status. Being tired, driving under the influence of alcohol or any other drugs and lacking experience are the factors that may result in or contribute to an accident; however, never can be associated with an AV.

5.1.2 Economic benefits

The difference between the monetary values of a brand-new car and that of its salvaged version after a severe traffic accident is quite clear. The amount is a loss to the personal, national, and global economy. While it is expected that AVs will reduce the number of accidents, this loss will also be prevented.

As mentioned in the first chapter, each year approximately 1.35 million people die as a result of traffic accidents, and injuries related to these accidents also cost most countries approximately 1–3% of their gross domestic products [22]. Since AVs are less prone-to-errors than humans, with a decrease in the number of accidents, we may also expect a lesser loss in GDP, in other words, an increase in the net GDP.

5.1.3 Social benefits

Besides its economic burdens, traffic accidents create severe physical and emotional impacts for surrenders of accidents who became disabled. Reducing the number of accidents will prevent these consequences [23].

Another social benefit of AVs is helping the disabled, elderly, children, and other people who are in need to be transported without the help of others [24]. This help will increase the rate of disabled and older people's contribution to the workforce. Eventually, those who were carried with AVs will reach what they need, and the overall quality of life of nations will increase.

5.1.4 Environmental impacts

A new discussion is about ownership of, and beyond it, sharing AVs. For future projections, there are expected two different styles of ownership models for AVs: public service and individual owning [25]. According to the first option, an AV will be owned by a private company or a governmental agency or a municipality. The second option means that an AV will be owned by a person and become his or her private property. The owner will be able to put his or her AV into the service of others. In this way, the owner will be able to compensate for the (high) cost of his or her AV. Another study on possible energy impacts of using AVs suggests that factors such as ridesharing, less time for looking for parking can reduce fuel consumption by 90% [26], which also means lower carbon emission.

5.2 The cons of AVs

5.2.1 Software-related problems

One of the most common concerns and critics against AVs is their reliability in the context of cybersecurity. As mentioned in Section 4 of this chapter, even a conventional, non-AV car can be hacked. Just imagine your personal computers and their vulnerability against viruses, trojans, and so on. Now, think about the security updates they receive. The same protection coming with security updates will be valid for your AV; however, its infection might be fatal. On the other hand, government agencies, security experts, and car manufacturers deliberately work to prevent any hacking.

Besides being hacked, another possible thing for an AV is having software deficiencies, also known as bugs. Just like any electronic devices, AVs may have flaws, too. However, since it is developer-related and common for every product of the same model, it is easy to detect and solve those deficiencies by debugging.

5.2.2 Privacy

AVs rely on data and their processing to drive safely; however, it becomes another serious concern regarding AVs: the possible violation of personal privacy by obtaining these data illegally.

An AV will have the ability to gather and process your personal data such as how you drive, whom you travel with, where you go, how much you stay there, whom you talk to on the phone, and so on. All these data might be used to analyze your personality traits or to track you. Furthermore, if these data are obtained by a criminal organization, it can also be used for blackmailing or any other cyber-crime against you.

5.2.3 Liability

Imagine that the car you drive collides with another vehicle. You stop, get off, and walk through the other vehicle to negotiate the accident with its driver. Suddenly, you see that there is no one in the car. After getting out of the shock, you notice that you had an accident with an AV. So, what is going to happen now? Who will be responsible or how will the responsibilities be shared between the driver (if exists), manufacturer, sensor producer, or programmer? Currently, lawmakers and government authorities work on it (up to a point).

In the USA, the federal government, via NHTSA, sets the rules for new motor vehicles and their equipment. These rules are known as Federal Motor Vehicle Safety Standards (FMVSSs), and NHTSA enforces FMVSSs to ensure that manufacturers comply with them [24]. Besides, federal governments do not act to create nation-wide legislation; however, requests state governments to regulate the responsibilities [24].

In Germany, a law for AV-related liability issues was put into action on June 21, 2017 [27]. The law makes the liability be shared between the manufacturer and driver. Drivers are allowed to avert their attention from driving but not to sleep [27]. Also, the law only keeps drivers responsible for an accident unless they take control of the car within an “adequate time reserve.” Nevertheless, this undefined “adequate time reserve” is still controversial [27].

It might be claimed in advance that the responsibility issue may remain as a concern, and it will be solved in time as long as AVs and their technology level developed.

5.2.4 Environmental issues

Besides possible effects resulted from factors such as ridesharing, negative factors may result in an energy consumption increase by up to 150% [26]. As long as AVs become safer, particular speed limits might be set for them, and those limits might also be increased gradually. Also, the comfort that AVs would provide to us might cause them to be used more frequently than before. Nevertheless, higher speeds or frequent use result in more fuel consumption, which also means an increase in carbon emissions.

5.2.5 Car sharing-related health issues

A recent pandemic caused hundreds of thousands of losses of human lives. Covid-19 proved that keeping physical (social) distance between people and following hygiene rules are crucial for avoiding contagions. Since it may not be possible to be sanitized between users, there would be a risk that AVs might be responsible agents for the spread of infection. If this happens, AVs would be banned for a while. In this case, severe health or transportation problems would be inevitable.

5.2.6 Financial-infrastructure burdens on states

AVs require certain elements to ensure awareness of their surroundings, such as traffic lights, dyed lanes, and traffic signs. In many underdeveloped or developing countries, unordered traffic may be witnessed. What if an AV comes to an intersection with no traffic lights, no lanes, no signs, cars moving bumper to bumper ignoring safe distance, and drivers not yielding? How could an AV determine the right of the pass in a situation like that?

To be able to have AVs on its roads, governments will have to order the traffic in their countries. They may also have to educate their citizens. Overall, this will become a financial burden because of the increase in spending on investments in transportation infrastructure and traffic education.

5.3 Moral issues with AVs

AVs mostly rely on AI technologies. However, as mentioned above, AIs can be attacked and misled easily. A 3D printed turtle was classified as an assault rifle by Google's Inception Classifier [28].

Another issue with AI is its moral dimension. Again, assume that an AV drives an individual or a group of people from someplace to another. Suddenly, a small child or an animal that is on the edge of extinction steps onto the road. There is no such possibility for AV to stop. Its only options are hitting itself to barriers and kill the passenger(s) it carries or killing the child or the animal in front of it. What do we expect from the AV to do in this scenario? Or if a human driver is seated behind the wheel, what do we expect from him or her?

People can be kept responsible for their behaviors and the consequences of those behaviors. Hence, after an accident resulting from a human driver's fault can be handled by law enforcement and judicial authorities easily. Nevertheless, when it comes to an accident caused by an AV, the situation changes. Because instead of instincts, education level, or experience, an AV acts on its codes compiled by someone.

The codes of an AV may change with its programmer's nationality. A study published on Nature was conducted upon scenario-based AV behaviors. The researchers managed to collect 39.61 million decisions made by thousands of people from 233 countries [29]. An online platform called Moral Machine has been shared in the domain of the Massachusetts Institute of Technology (MIT). The Moral Machine reached people in 10 different languages and asked them questions related to the actions of AVs in 13 different scenarios.

With the first question, people are asked to answer what an AV should do in case of sudden brake failure at a pedestrian crossing. Omitting whom it carries, the AV is supposed to hit and kill:

- two pedestrians – a homeless person and a woman – who are violating the law by crossing on red and

- two male executives crossing the street on the green abiding by the law.

Upon completing the questions, people are also given an option to enter their demographic data. In the end, results are shared, and people can have a chance to compare their standings to the general average of others.

Some of the findings of the study are as follows:

- **Globally;** humans, more lives, and younger people are preferred to pets, single life, and older people, respectively and
- **Culturally;** when people are clustered by their geographic and cultural proximity, people from
  - **Western countries** [North American and European (protestant, catholic, and orthodox Christian)] give higher importance to humans over the pets more lives over the single life, young over old, and fit over less fit;
  - **Eastern countries** [Confucianist (i.e., Japan and Taiwan) and Islamist (i.e., Indonesia, Pakistan, and Saudi Arabia)] give higher importance to pedestrian over (AV) passenger, humans over the pet, and law-abiding over law-violating; and
  - **Southern countries** (France, French-influenced, and Latin American) give higher priority to females over males, fit over less fit, higher status over lower status, young over old, and more lives over the single life.

These findings may lead us to ask this question: Should these types of differences and concerns be taken into account by manufacturers? Barbara Wege from Audi implies the importance of this type of studies [30]. From the legislative perspective, the first ethical guideline regulating AVs was published by the Ethics Commission of Germany's Federal Ministry of Transport and Digital Infrastructure in 2017 [30]. This guideline brings some regulations on decisions that would be made by AVs in future. Article 7 under the section titled "Ethical rules for automated and connected vehicular traffic" of this report is an example of this topic [31]:

> *"... within the constraints of what is technologically feasible, the systems must be programmed to accept damage to animals or property in a conflict if this means that personal injury can be prevented."*

From the perspective of potential buyers, the results of a study on the social dilemma of autonomous vehicles prove the complexity of the topic: People prefer AVs to be programmed to sacrifice its passengers for the greater good. The same people would like other people to buy these AVs; however, they also prefer to buy an AV that protects its passengers at all cost [32].

6. Legal concerns

AVs are supposed to decrease the number of accidents and improve safety for people. However, accidents involving AVs happen, and some of them even be fatal. While in some cases those accidents have been alleged to stem from human errors, questions arise for the safety of AVs and eyes turn to government authorities to see how they regulate AV testing and deployment procedures.

A study published on Transport Reviews by Taeihagh and Lim provides a detailed analysis of how selected states regulate the main issues related to AVs: safety, liability, privacy, cybersecurity, and industrial risks [33]. The study also groups the strategies implemented by states chosen into five groups, as well:

- **No-response;** due to the uncertainty of the situation, policymakers do not take any action.
- **Prevention-oriented;** policymakers set preventive regulations to avoid risks.
- **Control-oriented;** the existence of risks is allowed; however, necessary steps are taken to control it.
- **Toleration-oriented;** policymakers clarify the steps to be taken in case of realization of risks.
- **Adaptation-oriented;** policymakers seek opinions to adopt regulations based on common sense.

Selected states are then categorized by their strategy implementations on four domains of safety, liability, privacy, and cybersecurity [33]. On the other hand, in Section 5 of this chapter, it was mentioned that the respondents of the Moral Machine survey were clustered under three different groups according to their geographical and cultural proximity: western, eastern, and southern countries. So, are there any relationships between the selected countries' AV strategies and their citizens' moral preferences?

To answer that question, first, the strategy implementation categories in [33] are reordered to represent the magnitude of their risk aversion (for human life losses) as follows:

0: Toleration/no response; **1:** Adaptation; **2:** Light control; **3:** Control; **4:** Prevention.

These numbers (or averages) are assigned to states to obtain their policy points. Then, the same states are assigned numerical values to obtain their moral value points, according to the answers their citizens provided in moral machine study. States are given two points each if their citizens give priority to humans over pet and more lives over single life. The results are shown in **Figure 4**.

Figure 4 shows a comparison of policy points of states and moral value points of their citizens. It was prepared by a primary data visualization method in the absence of enough data for further statistical analyses. However, the figure still

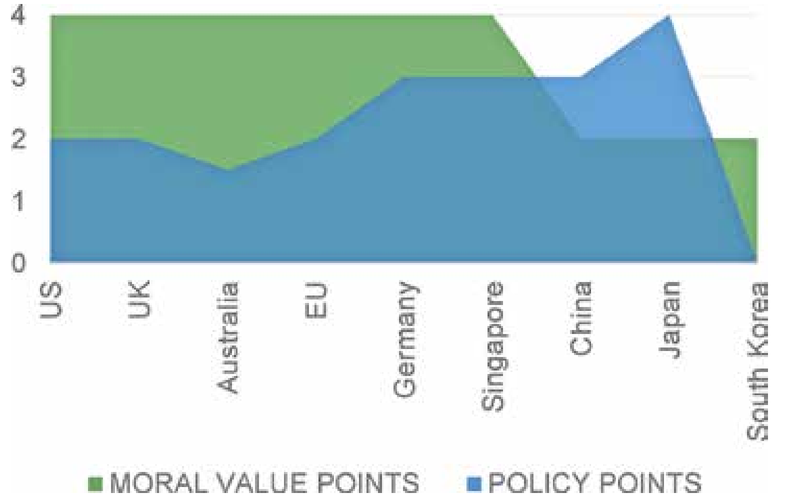


Figure 4.
Comparison of moral value and policy points.

helps us compare states' preferences on policymaking and their citizens' moral values, to an extent. For instance, people in the USA and the UK give higher priority to humans over pet and more lives over single life and get four moral value points, while the governments of both the USA and the UK implement light control strategies and get two policy points.

This situation may be explained by the governments' focus on innovation rather than safety. Elaine L. Chao, Secretary of the US Department of Transportation, touched upon this by saying "The U.S. Department of Transportation has a role to play in building and shaping this future by developing a regulatory framework that encourages, rather than hampers, the safe development, testing and deployment of automated vehicle technology" [24]. Similarly, Claire Perry, O'Neill, the former Parliamentary Under-Secretary of Department for Transport, claimed that "This review concludes that our legal and regulatory framework is not a barrier to the testing of automated vehicles on public roads … I believe we have one of the most welcoming regulatory environments for the development of this technology anywhere in the world" [34].

Contrary to the USA and the UK, Japan and China have lower moral value points than policy points. It can be explained with two views. First, from the moral value perspective, it might be suggested that these states have eastern cultures, and while they give higher importance to people over the pet, they do not give importance to more lives over single life [29]. Second, from the policymaking perspective, Japan, among the states of concern in **Figure 4**, is the most conservative state. The AV test procedures of Japan prove it. In accordance with Japan's drafted regulations, to test an AV in Japan, a driver with license must be seated, police approval and even a police officer in AV must exist, clear markings must be placed on AV, and driver must be ready to brake anytime [35].

China's situation is different from other countries. It applies preventive and light-control-oriented policies together [33]. While aiming to become a world leader in electrical and autonomous vehicle market [36], and to be able to compete with the USA, China implements low-control policies [33]. On the other hand, when it comes to allowing AVs to be tested on public roads, China sets preventive measures [33].

South Korea, one of the major car exporters, is categorized as an eastern state; however, it acts differently from all selected states by not regulating safety issues. Nevertheless, it created a council to ensure the harmony between its ministries [33]. Since there are not any international standards which are agreed on, South Korean government is waiting for it to be realized in order to set its own standards, which will be harmonized with international standards [33].

7. Conclusion

Today, thousands of AVs are on roads. Besides, that number is anticipated to climb up, and AVs are expected to constitute 25% of cars worldwide in 2035 [37]. This chapter tried to find an answer to the question of whether AVs prevent traffic accidents. After providing information about the history, general description, and working process of the AVs, their pros, cons, and moral perspectives have been presented. It might easily be suggested that AVs are more advantageous than human drivers in certain areas: an AV is better in obtaining and maintaining situational awareness. It never feels fatigued, gets tired, and works under the influence of alcohol. Because of these advantages, we may expect that AVs to reduce the number of accidents. In addition to their possible contribution to accident prevention, we will also enjoy their economic and social benefits and positive environmental impacts.

On the other hand, AVs have several disadvantages, too. For instance, they might have software problems, or they could be hacked. Overall, as Nidhi Kalra spoke in her testimony in the US Senate, in 2016, "there is no proven, feasible way to determine autonomous vehicle safety" [38].

Today, there is not a global consensus on the safety level of the AVs. Aside from a global level, even at a national level, it is hard to find common ground. As shown in Section 6, expectations from AVs' safety levels differ from country to country, but there are even gaps between the government policies and the expectations of their citizens. However, as long as AVs are tested, and the test data are shared, processed, and used for improvisation globally, AVs will be more likely to be developed and their possibility to prevent accidents will rise.

Thanks

Endless thanks and loves to my eternal love Serap, my lion son Görkem Dennis, and my little princess Kumsal Deniz.

Also, I remember the late Turkish academician Ord.Prof.Dr. Cahit Arf with gratitude for his contributions to Mathematics and his efforts to enlighten our society by explaining how a machine could think in a public conference in 1959, as well [39].

Abbreviations

AI	artificial intelligence
AV	autonomous vehicle
CNN	convolutional neural network
DARPA	defense advanced research projects agency
DNN	deep neural network
EU	European Union
FMVSSs	federal motor vehicle safety standards
MIT	Massachusetts Institute of Technology
NHTSA	national highway traffic safety administration
NQE	national qualification event
LIDAR	light detection and ranging
RADAR	radio detection and ranging
SAE	society of automotive engineers
SDC	self-driving car
SONAR	sound navigation and ranging
UGV	unmanned ground vehicle
UK	United Kingdom
US	United States

Author details

Caner Filiz[1,2]

1 Baskent University, Ankara, Turkey

2 Gendarmerie and Coast Guard Academy, Ankara, Turkey

*Address all correspondence to: canerfiliz.1@gmail.com

References

[1] Road traffic injuries [Internet]. World Health Organization. 2020. Available from: https://www.who.int/en/news-room/fact-sheets/detail/road-traffic-injuries [Accessed: 20 April 2020]

[2] Automated Vehicles for Safety [Internet]. National Highway Traffic Safety Administration. 2020. Available from: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety [Accessed: 22 April 2020]

[3] What causes traffic accidents? [Internet]. Available from: https://www.koroad.or.kr/en_web/view/trfEnv4.do [Accessed: 05 February 2020]

[4] National Motor Vehicle Crash Causation Survey (Report to Congress). Springfield, VA: National Technical Information Service; 2008

[5] Top 25 Causes of Car Accidents [Internet]. Available from: https://seriousaccidents.com/legal-advice/top-causes-of-car-accidents/ [Accessed: 10 February 2020]

[6] Rolison JJ, Regev S, Moutari S, Feeney A. What are the factors that contribute to road accidents? An assessment of law enforcement views, ordinary drivers' opinions, and road accident records. Accident; Analysis and Prevention. 2018;**115**:11-24

[7] Self-Driving Cars Explained [Internet]. Union of Concerned Scientists. 2017. Available from: https://www.ucsusa.org/resources/self-driving-cars-101 [Accessed: 30 April 2020]

[8] SAE International Releases Updated Visual Chart for Its "Levels of Driving Automation" Standard for Self-Driving Vehicles [Internet]. SAE International. 2018. Available from: https://www.sae.org/news/press-room/2018/12/sae-international-releases-updated-visual-chart-for-its-%E2%80%9Clevels-of-driving-automation%E2%80%9D-standard-for-self-driving-vehicles [Accessed: 01 May 2020]

[9] Bassett A. The Emergence of Driverless Cars [Internet]. Encyclopædia Britannica. Encyclopædia Britannica, inc. 2015. Available from: https://www.britannica.com/topic/Emergence-of-Driverless-Cars-The-2045163 [Accessed: 01 May 2020]

[10] Asimov I. Sally. May–June. Fantastic. Schenectady, NY: Ziff-Davis Publishing Company; 1953

[11] The DARPA Grand Challenge: Ten Years Later [Internet]. Defense Advanced Research Projects Agency. 2014. Available from: https://www.darpa.mil/news-events/2014-03-13 [Accessed: 02 May 2020]

[12] Hooper J. From Darpa Grand Challenge 2004: DARPA's Debacle in the Desert [Internet]. Popular Science. Popular Science. 2004. Available from: https://www.popsci.com/scitech/article/2004-06/darpa-grand-challenge-2004darpas-debacle-desert/ [Accessed: 02 May 2020]

[13] The Grand Challenge [Internet]. Defense Advanced Research Projects Agency. Available from: https://www.darpa.mil/about-us/timeline/-grand-challenge-for-autonomous-vehicles [Accessed: 03 May 2020]

[14] Urban Challenge [Internet]. Defense Advanced Research Projects Agency. Available from: https://archive.darpa.mil/grandchallenge/ [Accessed: 03 May 2020]

[15] Artificial Intelligence [Internet]. Merriam-Webster. Available from: https://www.merriam-webster.com/dictionary/

artificialintelligence?utm_campaign=sd [Accessed: 06 May 2020]

[16] Tsyktor V. Lidar vs Radar vs Sonar: Which is Better for Self-Driving Cars? [Internet]. Cyber Pulse. 2020. Available from: https://cyberpulse.info/lidar-vs-radar-vs-sonar/ [Accessed: 06 May 2020]

[17] Comiter M. Attacking Artificial Intelligence: AI's Vulnerability and What Policymakers Can Do about it. Cambridge, MA: HARVARD Kennedy School Belfer Center; 2019

[18] Eykholt K, Evtimov I, Ferdinand E, Li B, Rahmati A, Xiao C, et al. Robust physical-world attacks on deep learning visual classification. In: 2018 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR 2018): Salt Lake City, Utah, USA, 18-22 June 2018. Piscataway, NJ: IEEE; 2018. pp. 1625-1634

[19] Greenberg A. Hackers Remotely Kill a Jeep on the Highway-With Me in It [Internet]. Wired. 2015. Available from: https://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/ [Accessed: 08 May 2020]

[20] Kessler AM. Fiat Chrysler Issues Recall Over Hacking [Internet]. New York. 2015. Available from: https://www.nytimes.com/2015/07/25/business/fiat-chrysler-recalls-1-4-million-vehicles-to-fix-hacking-issue.html [Accessed: 08 May 2020]

[21] Vehicle Cybersecurity [Internet]. NHTSA. Available from: https://www.nhtsa.gov/technology-innovation/vehicle-cybersecurity [Accessed: 08 May 2020]

[22] Dalal K, Lin Z, Gifford M, Svanström L. Economics of global burden of road traffic injuries and their relationship with health system variables. International Journal of Preventive Medicine. 2013;**4**(12):1442-1450

[23] Blincoe LJ, Miller TR, Zaloshnja E, Lawrence BA. The Economic and Societal Impact of Motor Vehicle Crashes. (Report No. DOT HS 812 013). Washington, DC: National Highway Traffic Safety Administration; 2015

[24] Automated Driving Systems 2.0 A Vision for Safety. [cited 10 May 2020]. Available from: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf

[25] Mourad A, Puchinger J, Chu C. Owning or sharing autonomous vehicles: Comparing different ownership and usage scenarios. European Transport Research Review. 2019:11-31

[26] Meyer G, Beiker S, Brown A, Gonder J, Repac B. An analysis of possible energy impacts of automated vehicle. In: Road Vehicle Automation. Cham: Springer International Publishing; 2014. pp. 137-153

[27] Burianski M, Theissen C. Germany Permits Automated Vehicles [Internet]. J. D. Supra. White & Case LLP; 2017. Available from: https://www.jdsupra.com/legalnews/germany-permits-automated-vehicles-15610/ [Accessed: 17 May 2020]

[28] Athalye A, Engstrom L, Ilyas A, Kwok K. Synthesizing robust adversarial examples. In: International Conference on Machine Learning. Stockholm; 2018. pp. 284-293

[29] Awad E, Dsouza S, Kim R, Schulz J, Henrich J, Shariff A, et al. The moral machine experiment. Nature. 2018;**563**:59-64

[30] Maxmen A. Self-driving car dilemmas reveal that moral choices are not universal [Internet]. Nature News. Nature Publishing Group. 2018.

Available from: https://www.nature.com/articles/d41586-018-07135-0 [Accessed: 11 May 2020]

[31] Automated and Connected Driving. Ethics Commission of Federal Ministry of Transport and Digital Infrastructure; 2017

[32] Bonnefon J-F, Shariff A, Rahwan I. The social dilemma of autonomous vehicles. Science. 2016;**352**(6293):1573-1576

[33] Taeihagh A, Lim HSM. Governing autonomous vehicles: Emerging responses for safety, liability, privacy, cybersecurity, and industry risks. Transport Reviews. 2018;**39**(1):103-128

[34] Summary Reports and Action Plan. London. 2015. (The Pathway to Driverless Cars)

[35] NPA drafts rules for testing driverless cars on public roads. The Japan Times [Internet]. 2017. Available from: https://www.japantimes.co.jp/news/2017/04/13/national/npa-drafts-rules-testing-driverless-cars-public-roads/#.XsGHgmgzbIV [Accessed: 17 May 2020]

[36] Dunne MJ. China Aims To Be No. 1 Globally In EVs, Autonomous Cars By 2030 [Internet]. Forbes. Forbes Magazine. 2016. Available from: https://www.forbes.com/sites/michaeldunne/2016/12/14/chinas-automotive-2030-blueprint-no-1-globally-in-evs-autonomous-cars/ [Accessed: 17 May 2020]

[37] Coren MJ. The car industry is heading towards a driverless future [Internet]. World Economic Forum. Quartz. 2017. Available from: https://www.weforum.org/agenda/2017/01/having-a-baby-this-year-a-robotics-expert-thinks-theyll-never-drive-a-car/ [Accessed: 20 April 2020]

[38] Shaping the Future of Autonomous Vehicles: How Policymakers Can Promote Safety, Mobility, and Efficiency in an Uncertain World. 2016

[39] Arf C. 1958-1959 Öğretim Yılı Halk Konferansları I. Erzurum: Atatürk Üniversitesi; 1959. pp. 91-103

Chapter 4

Novel Approach in Tunnel Safety Assessment

Peter Vidmar

Abstract

The definition of a deterministic approach to risk analysis stems from the need to understand the conditions that are developed in the event of an accident with a fire in a road tunnel. From the point of view of the tunnel manager and rescuers, these data are important during planning the operation of the tunnel and in coordinating the rescue. The methods of tunnel control in crisis situations are most often based on the experience of operators and crisis plans, which are also made by experience or using simple calculation tools. In recent years, due to many tragic accidents in European tunnels, there has been a lot of talk and work in the field of risk assessment and the possibilities of risk reduction. The methodology of safety analyses and the determination of the level of risk arise predominantly from the nuclear and chemical industry, where it has been in use for more than 50 years. The paper presents the methodology for integrating methods of rapid processing of risk assessment with time-consuming CFD methods for analysing the consequences of fire in the tunnel safety assessment process. The main observed variables are the density and the temperature of the carbon black, which are analysed during the fire step in a minute. Human behaviour is considered in the evacuation model, which is necessary for the assessment of fatalities during the progress of the fire. The use of the methodology is presented by assessing the national tolerable risk for transport in tunnels and compared to the EU reference criteria.

Keywords: tunnel safety, fire safety, risk assessment, F-N curves

1. Introduction

Risk assessment studies and specifically fire consequence analyses are likely applying fast computation models [1]. A risk assessment is a multicriteria process that requires a network approach for process and hazard identification. The events are systematically analysed with a Bayesian network, event tree, fault tree and other well-known approaches [2]. The gap in most risk assessment approaches is the connection between a systematic risk identification and a precise calculation of fire consequences. The main reason for that is the incompatibility of approaches. The risk identification for tunnel safety operation is usually presented with a number of scenarios that are further divided into sub-scenarios for different fire sources and locations, types of ventilation, traffic density, etc. The result is a large number of scenarios that are not suitable for CFD calculation, not so much because of computation time, but because results are more suitable for deep hydrodynamic analysis than for the identification of risk for a person or a group of people inside a tunnel.

After the entering in force of EU directive 2004/54/EC [3] on minimum safety requirements for tunnels, the risk assessment methods have been proposed by PIARC [4] with the QRAM model [5]. Other tools and methodologies for risk assessment in road tunnels were developed—the Dutch RWQRA model and the Austrian RVS 09.03.11-TuRisMo methodology. The fire consequence calculations, as a main part of risk evaluation, are done with a simple one-dimensional flow model or at most with zone models, where in every step volume is divided into a hot and cold layer. These models cannot cover a specific flow dynamic, smoke stratification, influence of different ventilation systems, vorticity, and crossflow. Effects like back layering are modelled directly in one-dimensional models, but its reliability is scenario dependent and is not reliable, or in other scenarios overestimated [6]. Following this idea, we believe that a methodology of fire safety valuation, which improves existing methodologies and is based on a deterministic approach, is necessary, as the approach to integrate CFD consequence results in a probabilistic QRA method [7].

The presented analysis includes the fire modelling based on CFD results [8, 9] for different standard fire scenarios and includes basic human behaviour, e.g. resistance on height temperature and gas concentration, evacuation velocity, reaction times and other features. These consequences are further multiplied with the probability (likelihood) of the same events, and the result is the individual risk for fatalities or injuries for fire events in tunnels.

2. Approach on tunnel safety

A risk assessment of a controlled system is much more reliable than the assessment of a "natural" one. Similarly to an industry process, where safety risk assessment has been introduced first, a traffic flow in a tunnel is a controlled process. The structure of the tunnel, the control of the traffic and safety systems are intended to keep control of all events that could happen in operational and emergency situations. The paper is focused mainly on fire events and the risk to people arising from it. Fire development and spread are complex phenomena, and CFD programs are reliable and useful for simulations. The authors [10–13] have done a large number of validation tests archiving the reliability of results in a range of 20–30% compared to experimental tests. The author [8] conducted validation tests of the program Fire Dynamic Simulator (FDS) with Memorial Tunnel experiment results. Results from this simulation are further used in this paper as the input for consequence level estimation.

The deterministic approach is used for the analysis of the greater part of physical events like fire source characteristic and its dynamics, the operation of the ventilation system and other conditions as well as their reciprocal interactions. The approach also leads to the definition of the technical system "safety efficiency" in the range of possibilities that exist in the real word and are functionally descriptive. When the approach is used in practice, we should define a number of "safety categories" based on event probability and consequences for individual risk. An example is presented in **Table 1**.

Note that in these schemes a quantitative definition is given in addition to the qualitative definition, mainly to ensure consistency in the course of the analysis and provide benchmarks (semi-quantitative analysis). In schemes of this type, the assessment team, usually comprising members of management, safety engineers and operations personnel, will first identify all hazards, using HAZID, HAZOP or similar approaches, and then assign a severity category to each of these, for both likelihood and consequences [14, 15].

Likelihood categories	Qualitative definition	Quantitative definition (times per year)
A	Once in a year	0.3–3
B	Possible but not likely	0.03–0.3
C	Unlikely	0.003–0.03
D	Very unlikely	0.0003–0.003
E	Remote	0.00003–0.0003
Consequence categories	**Qualitative definition**	**Semi-quantitative definition**
1	Catastrophic	Multiple fatalities
2	Major	Single fatality, multiple injuries
3	Very serious	Permanently disable injuries
4	Serious	Serious injury, full recovery
5	Minor	Lost time injury, short absence from work

Table 1.
Deterministic safety analysis: supposed safety categories.

Following the assumptions in **Table 1**, a "risk matrix" would then be defined as a 5 × 5 matrix with each side corresponding to one severity category.

Different shading in a table indicates different risk levels. Hazards with high risk, such as A1, B1 and A2 in the black squares, are thought of as being very severe and require immediate action to reduce a risk. Hazards with low risk, such as E5, E4 and D5 in white squares, are considered to require no further action. Hazards between these two are considered worthy of some improvement if a cost-effective solution can be found.

The two methods of risk analysis (qualitative and quantitative) are often not separable but upgrade each other. **Figure 1** shows the event tree for the example of a fuel leak from a heavy goods vehicle. The quantitative approach is applied because the event probabilities are known from past statistics. The results of the event tree

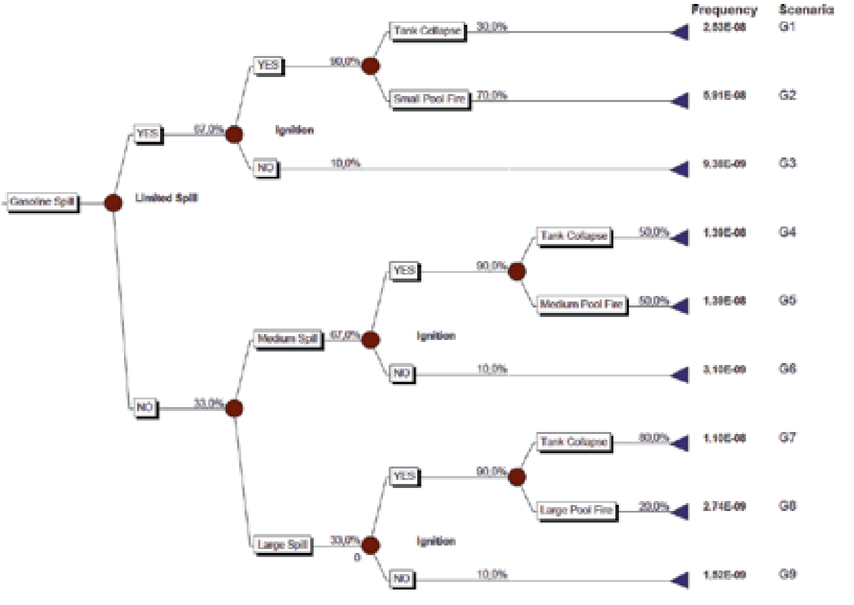


Figure 1.
Event tree for fuel leak out scenario [16].

are several predicted scenarios with calculated final event frequencies. Among nine final scenarios, there are three fire scenarios with a major frequency: G2, G5 and G8. Further work leads to two directions, with a probabilistic or deterministic approach. In the following sections, the methodology and requirements of using a deterministic approach are explained more in detail and developed from this event tree scenario.

2.1 Tunnel fire modelling and simulations

The application of CFD model on tunnel geometry is a demanding task but has been widely validated. Fire dynamics is a three-dimensional, time-dependent process which integrates the interactions among combustion, fluid flow and heat transfer processes. The turbulence process of energy dissipation over which fire dynamics evolve is of the order of 0.1 s and 1 mm, respectively [17, 18], but lengths of realistic tunnels are measured in kilometres. This implies that the turbulence needs to be algebraically modelled.

A good mathematical approximation of the fire is done by a combustion model (instantaneous reaction when fuel and oxygen are properly mixed), radiation model (non-scattering grey gas model) and low Mach variable density formulation of the fluid conservation Eqs. A Fire Dynamics Simulator (FDS) program uses the combination of these models for simulating fire development and smoke spread. The fluid flow is modelled by solving the basic conservation equations: the conservation of mass (1), conservation of mixture fraction Z (2), conservation of momentum (3) and conservation of energy (4) using a form for low Mach number [17]. The approximation involves the filtering out of acoustic waves. The basic conservation equations are written in the form:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \boldsymbol{u} = 0 \tag{1}$$

$$\frac{\partial \rho}{\partial t}(\rho Z) + \nabla \cdot \rho Z \boldsymbol{u} = \nabla \cdot \rho D \nabla Z \tag{2}$$

$$\rho\left(\frac{\partial \boldsymbol{u}}{\partial t} + \frac{1}{2}\nabla|\boldsymbol{u}|^2 - \boldsymbol{u} \times \omega\right) + \nabla \tilde{p} = (\rho - \rho_\infty)\boldsymbol{g} + \nabla \cdot \tau \tag{3}$$

$$\rho c_p\left(\frac{\partial T}{\partial t} + \boldsymbol{u} \cdot \nabla T\right) = \dot{q}_c''' - \nabla \cdot \boldsymbol{q}_R + \nabla \cdot k \nabla T \tag{4}$$

and the equation of state

$$p_0 = \rho R T \tag{5}$$

where ρ is a density, **u** is a velocity vector, Z is the mixture fraction, T the temperature, p_0 the ambient pressure, R the gas constant, c_p is a specific heat and D the molecular diffusivity. $\tilde{p}$ is the perturbation pressure caused by pressure differences, τ the viscosity stress tensor and k the thermal conductivity. $\dot{q}_c'''$ and $\nabla \cdot \boldsymbol{q}_R$ are the source terms of chemical reaction and radiation, respectively. The radiation term has a negative sign because it represents a heat sink [17]. The effect of the flow field turbulence is modelled using large eddy simulation (LES), in which the large-scale eddies are computed directly and the sub-grid scale dissipative processes are modelled [18, 19]. The unknown sub-grid stress tensor τ is modelled by a Smagorinsky model.

2.2 Parameters and approach to the result analysis

The simulation results are presented on levels of fire force, and different types of tunnel ventilation are shown. The consequences of the distance of the smoke and temperature are qualitatively evaluated from the velocity and temperature field. People using the tunnel are exposed to the risk after the fire starts, but not only them. The evacuation procedure is mainly left to the people's decision but mostly supported by a tunnel safety system like light signs, pictograms and sound signals. The successful evacuation is supported by the efficient ventilation fire protocol. Factors like the time of the beginning of evacuation, evacuation speed, start of ventilation protocol and the distance to cross passages are the keys to reducing personal risk. Especially for large fires, the risk of exposure to smoke is present when the smoke movement is faster than the average evacuation speed. The most risky examples are when the people do not start with the immediate self-rescue procedure after the start of the fire and when the ventilation protocol is not suitable for that fire source [20]. The other risk criterion is high temperature, which usually has a lower contribution to the risk than smoke. In most cases this depends on ventilation. The limit value of the concentration of smoke particles (PM10 heavy particles with the diameter up to 10 μm) is 1000 mg/m^3, and the limit temperature is 50°C [21]. The smoke particles are less problematic from a toxic point of view than other combustible products (CO_2, carbon dioxide; CO, carbon monoxide; HCN, hydrogen cyanide; HCl, hydrogen chloride; etc). Their share of concentration is conditional and often very similar. From different experiments in the Memorial Tunnel, it can be found, for example, that concentrations of smoke particles and CO are in relation around 10:1. A similar relation can be also found in toxic levels of these products. Lethal concentration 50% (LC_{50}) for soot particles is 30 g/m^3 in a 30 min exposure or 1–3 g min/m^3 LC_{50}; for CO it is 2000–3500 ppm, which is 2300–4000 mg/m^3 in a 30–60 min exposure [21]. The limit temperature values of human resistance are, according to Gann and Hall, 100°C for 30 min and 75°C for 60 min of exposure. Because this information is true for an adult man, it is the most optimal. But within the same study, the authors point out difficulties in breathing already at 65°C of air temperature. Taking this into account, there are two values that are used in our result analysis. The chosen limit concentration of smoke particles is 1000 mg/m^3 and the limit temperature is 50°C.

The risk or consequences are divided into five categories shown in **Table 2**.

A further step is the interpretation and the quantification of the human resistance limits to the actual risk levels. The sub model developed during the research analyses of CFD results and according to the following logical conditions marks every 1-minute time step along the entire tunnel length. Using this approach all the influences of the tunnel geometry, fire source and ventilation are considered in the risk evaluation:

	Risk category	Consequence severity	Percent of fatalities every 1 min exposure
1.	LR–low risk	Lesser injury	0.1%
2.	MR–medium risk	Serious injury with full recovery	2%
3.	SR–serious risk	Permanent injury	8%
4.	VHR–very high risk	Low casualty number (1–3), numerous injured	20%
5.	EHR–extremely high risk	Numerous casualties	50%

Table 2.
Risk category and consequences applied in the analysis.

LR: ASD $<$ 500.
MR: ASDL $>500 \wedge$ SLH $>$ ASLH.
SR: ASD $>$ 500.
VHR: ASDL $>500 \wedge$ SLH $<$ ASLH.
EXR: ((SR $\vee$ VHR) $\wedge$ AT >50) $\vee$ ATL $>$ 50.
where the abbreviations mean:
ASD-average smoke density value in profile [mg/m^3].
ASDL-average smoke density value in layer [mg/m^3].
SLH-smoke layer height [m].
ASLH-allowed smoke layer height [m].
AT-average temperature in profile [°C].
ATL-average temperature in layer [°C].

The CFD simulation results are discreet in space and time with extremely small time and space steps. The analysis of so much information is usually done in a graphic form representing a variable (temperature, soot density) field for a steady-state result or with a time-dependent variable value for an observed location of the geometry. From the safety point of view, such a large quantity of information becomes unclear and less useful. To evaluate the risk for a person in a tunnel, the output files of a temperature field and soot density are first properly averaged to a series of zones that a moving person occupies during his movement. The space is thus averaged in length and most importantly in height. In height the variable fields are averaged in four layers, the height of each being about 1.5 metres. This height is redefined in a model as the allowed layer height. One condition for the extreme risk is that the average temperature in this lower layer exceeds 50°C for 1 minute.

2.2.1 Evacuation model

The discussion of results is enforced with the understanding of the human behaviour during the fire in the tunnel after they begin with the self-rescue procedure. This is the evacuation from the tunnel portal or through the first transverse passage in two tube tunnels. The movement of the people in similar conditions is very unpredictable; some become immediately aware of the danger and begin with the self-rescue procedure, while others do not perceive the danger in time and begin late with the self-rescue procedure. A simplified model of human movement is introduced to the risk model. The model takes into consideration the elementary movement parameters as start of the self-rescue, walking speed, tunnel length and the direction of the movement according to the location of the fire. This means the evacuation can only lead away from fire. The model allows the analysis of movement from different starting locations which allows the division of the tunnel into zones depending on the location of cross passages. The calculated locations of persons are then used for checking the temperature and the smoke concentration, and consequently the level of the individual risk is evaluated according to the previous approach.

3. Model validation

This section presents the FDS model validation with experimental data from the Memorial Tunnel test program from 1993 to 1995 in the USA. The experimental tunnel is 853 m long and 7.9 m in height with a 3.2% slope. Many tests have been conducted with different fire source powers and different ventilation programs. The validation presents two different validation scenarios: a 50 MW fire with natural ventilation and a 100 MW fire with forced longitudinal ventilation. The fuel used in the experiment and simulated is oil filled into a flat container [22, 23]. Using the same fuel, different fire heat release rates are obtained by changing the burning surface.

3.1 Geometry of the model

The geometry, initial and boundary conditions are arranged to the tunnel geometry and fire parameters. **Figure 2** shows the geometry of the tunnel from the external view. The upper closure is just few metres long and is a ventilator room. The fire is located 615 m from the west portal and is symmetrical to the cross section. The fire is assumed as a heat release source with a specific power 2700 kW/m^2, where the oxygen and fuel consumption and the release of combustion products depend on the stoichiometric equation $11\ O_2 + C_7H_{16} \rightarrow 7\ CO_2 + 8\ H_2O$. Here C_7H_{16} is a heptane, which burns very similar to a diesel oil just with less soot release. This is additionally added as a product to the combustion model.

3.2 Initial and boundary conditions

Initial and boundary conditions are divided into geometry obstacle conditions and fluid conditions. The walls of the tunnel are defined as thermally thick walls in the model, where heat transfer is computed to and through the walls. The initial temperature of any obstacle is defined the same as ambient (20°C) temperature. The velocity at the wall is calculated as the average value of the velocity in the first cell that touches the wall and zero velocity on the wall cell. The heat release from the fire source is defined as full power at the beginning of the simulation, because data available from the experiment are only for fully developed fires [24]. Thermal radiation initial conditions are defined with radiation intensity based on the initial temperature of objects (ambient temperature) and the energy absorption in the air, mostly formed by nitrogen. The heat of radiation emitted from walls is calculated as black wall radiation intensity [25].

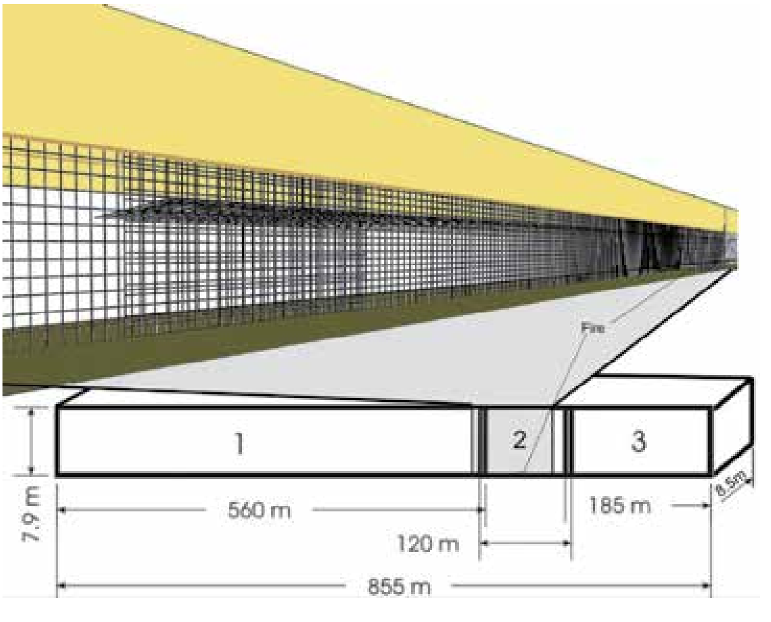


Figure 2.
Geometry and mesh setup.

The model simulates the 3.2% tunnel slope with the additional gravity vector component in the direction of the slope of 0.314 m/s^2. The portals are defined as open boundary conditions that link the tunnel domain with the ambient.

The applied numerical grid is non-uniform. The geometry is divided into three sections over the tunnel length: 560, 120 and 185 m. A 50 MW fire model applies 800,640 cells and a 100 MW model 1,274,220 cells. The reason is the requirement of the combustion model, which computes the reaction and the heat release in the second section where the fire is located. Other parts of the geometry do not require such a dense grid because of lower velocity gradients.

3.2.1 Simulation results

The compared data presented here are temperatures measured with thermocouples in the experiment and observed in a simulation. There are 14 observation points selected at 2.5 and 6.5 metres from the floor placed every 100 metres from the left portal (**Figure 2**).

The maximum deviation is within the first 400 seconds of the simulation, after that time the calculated values come closer to the measured ones. Measuring points that measure temperatures on the downwind side (TC 208 and TC 73) of the fire vary considerably, since these errors are greater than 100°C. This measurement is not a representative, since the calculated back layer varies just 10 metres from that measured. The values on TC 202 and TC 66 are very representative, which are closest to the fire on the upwind side. At the initial stages of the fire (up to 400 s), the deviation is large, namely 50–100% or 30–100°C. The errors are reduced after 400 s and reach the values $\pm$ 15°C until the end of the simulation (900 s). The deviations at other measuring points are at the end of the simulation of the order of magnitude from −10 to +50% or temperature differences from −10 to +30°C.

Figures 3 and **4** shows the deviation of the simulated values from the experimental ones for each measuring point for 50 MW and 100 MW fire respectively. The largest deviation is at the measuring points TC 200 and TC 202, which are located upwind of the fire, because the calculated reverse current is greater than on the experiment. The fluctuation in the deviation of the results is visible over a period of

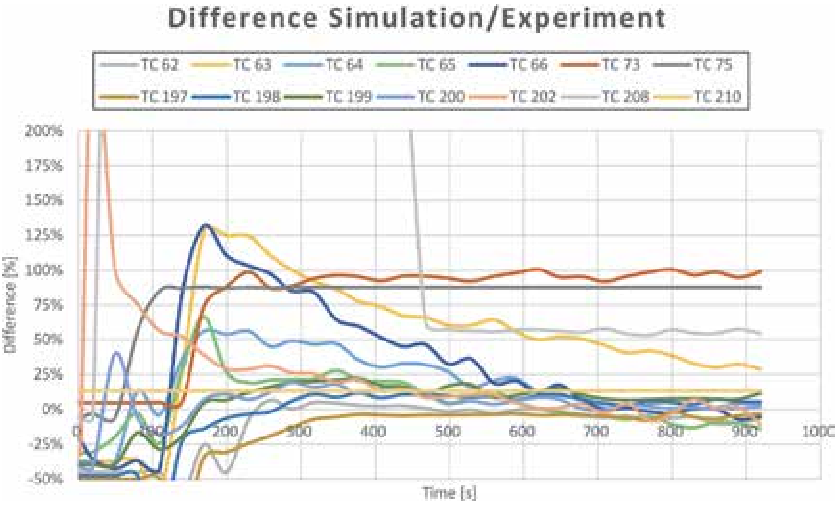


Figure 3.
Deviation of simulation results from experimental data in % for 50 MW fire.

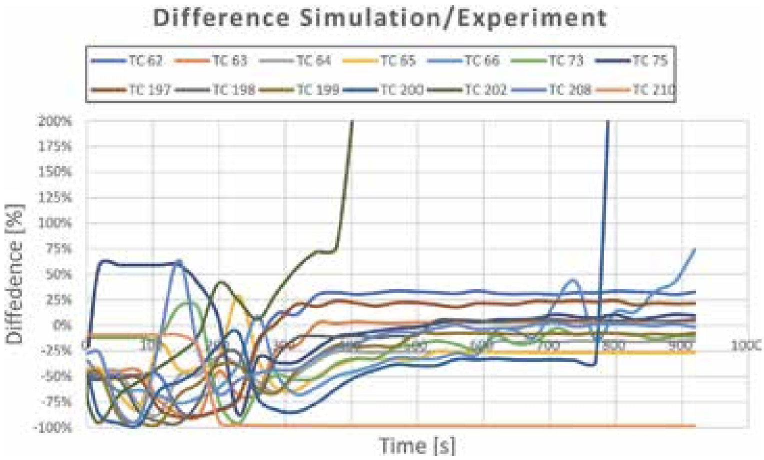


Figure 4.
Deviation of simulation results from experimental data in % for 100 MW fire.

200–400 s, which occurs during the transient of the fan turnover, and consequently there is a change in the direction of flow against the buoyant flow. The comparison of the values on the downwind side of the fire at the measuring points TC 208, TC 73 and TC 75 shows deviations in the range of ±15%, which is satisfactory for us.

The conclusion from comparing the results is that the model geometry, initial and boundary conditions and the setting of the numerical grid conform to the numerical requirements for the calculation of fluid dynamics inside the tunnel, against the experimental data. The obtained information is further used in the preparation of other similar models.

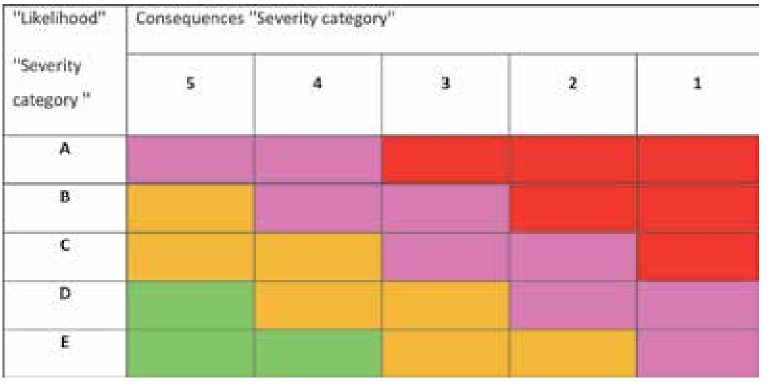
4. Tunnel fire and risk analysis

The risk assessment methodology presented here is based on the analysis of CFD model results. The reliability of the methodology is proven with model results and numerous scenarios, where the whole spectre of tunnel fire scenarios is assessed, considering different types of ventilation and different fire intensity. Other parameters, like environmental influence, traffic density and other characteristics of the tunnel, are handled separately [26].

The idea is based on the development of a deterministic risk matrix as presented in **Table 3** based on CFD results. The safety category is represented by the power of the fire and the type of ventilation where the consequences are evaluated in the time during the progress of the fire [27, 28]. The risk criteria are defined as a relation between the hot smoke layer height, the distance from the fire location and the evacuation time of the users. In the case the speed of the smoke is greater than the speed of the evacuation and in case the thickness of the hot layer is higher than the height of the person during the evacuation, the risk is high.

4.1 Tunnel fire scenarios

All together 12 tunnel fire scenarios are processed. Three levels of fire are simulated, each with four different types of ventilation. The span of the fire source is from 20 MW, 50 MW to 100 MW, while the ventilation is sorted from the less to the more effective: (1) natural, (2) longitudinal, (3) semi-transverse and (4) transverse or improved transverse ventilation.



"Likelihood" "Severity category "	Consequences "Severity category"				
	5	4	3	2	1
A					
B					
C					
D					
E					

Table 3.
Deterministic safety analysis: Generic example of risk matrix.

The section of the simulated tunnel is 650 m long, 10 m wide and 8 m in height or 6 m when the roof is lowered for transverse ventilation. The fire is located at a distance of 350 m in all the models, differing only in the size of the burning area. Findings from validation tests are used and implemented also in the following scenario of the definition of initial and boundary conditions of the model and proper numerical discretization.

4.2 Fire simulation

The calculation of the 12 presented scenarios is done on a cluster of four computers—PC 2.8 MHz with a join memory capacity of 32 GB. The discretization of each model is from 800,000 to 1,400,000 mesh points. The numeric and sensitive analysis of the model was conducted but is not presented here. After multiple simulation repetitions, calculation times comparisons and result validations, an optimal relation between numerical grid density, calculation time and result reliability has been obtained.

The definition of the initial and boundary conditions is different for each model but based on findings from the validation models. Four different ventilations are defined: natural, longitudinal, semi-transverse and transverse. The tunnel models with natural and longitudinal ventilation take the whole section of the tunnel; the tunnel models with semi-transverse and transverse ventilation consider only the light section of the tunnel (without the ventilation ducts).

4.3 Results

The presentation of the results in a form of temperature of smoke concentration field can provide useful information only to an experienced user but yields unclear information about a true risk. Results of simulation are therefore processed for each scenario according to the criteria from paragraph 2.2. The temperature and smoke values are the most influential risk parameters in the tunnel. According to the human resistance criteria, the individual risk is calculated and presented in a descriptive form low risk (LR) to extreme high risk (EXR). The presence of smoke on the individual location influences the first four levels of risk, depending on concentration; the presence of high temperature contributes to an additional (the highest) risk level. **Table 4** presents a deterministic risk matrix for a constant location in a tunnel during a fire that is 252 m north of the fire. The picture is very representative because it confirms the theory on safety analyses from

DOI: http://dx.doi.org/10.5772/intechopen.90494

Safety Category		Consequences														
Power	Ventilation	60	120	180	240	300	360	420	480	540	600	660	720	780	840	900
c		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20 MW	Transverse	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR
		LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR
	Semi Transverse	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR
		LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR
	Longitudinal	LR	MR	MR	MR	MR	MR	MR	MR	MR	[illegible]	LR	LR	LR	LR	LR
		LR	MR	MR	MR	MR	MR	MR	MR	MR	[illegible]	LR	LR	LR	LR	LR
	Natural	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR
		LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR
50 MW	Transverse	LR	LR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LR	LR	LR	LR	LR
		LR	LR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LR	LR	LR	LR	LR
	Semi Transverse	LR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LR	LR	LR	LR	LR
		LR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LR	LR	LR	LR	LR
	Longitudinal	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR
		LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR
	Natural	LR	LR	LR	LR	LR	LR	LR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LR
		LR	LR	LR	LR	LR	LR	LR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LR
100 MW	Transverse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LR
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LR
	Semi Transverse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Longitudinal	LR	LR	LR	LR	LR	LR	LR	LR	[illegible]	[illegible]	LR	LR	LR	LR	LR
		LR	LR	LR	LR	LR	LR	LR	LR	[illegible]	[illegible]	LR	LR	LR	LR	LR
	Natural	LR	LR	LR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		LR	LR	LR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4.
The deterministic risk matrix for the chosen observer location.

Section 2, that is, the individual risk increases with fire size and evacuation time. Further, for the largest fire, the contribution to the risk of the ventilation may be observed.

Table 4 is made as a functionally dependent dynamic matrix that selects the calculated values from the database of CFD processed results. The matrix model allows the selection of the observed location and then calculates the risk. According to the evacuation model, the start position—the beginning of the self-rescue procedure and the walking speed—is defined, and the users' movement may be observed as the smoke concentration and the temperature height to which tunnel users are exposed. The individual risk is therefore calculated.

5. Risk assessment using CFD results

CFD simulation results could provide relatively accurate information on fire dynamics. As presented in Section 2 there is a possibility to connect the deterministic approach to a probabilistic approach. I especially refer to the consequences as they are shown in **Table 1**. The processed results from tunnel modelling as presented in a risk matrix are quantified first according to **Table 1**. The information presents the quantification of risk that is taken as a final result of the risk during a tunnel fire or as an input for the continuation of events in the event tree assessment of the risk.

The continuation of the event tree from **Figure 1** for the G2 scenario is presented in **Figure 5**.

The use of a deterministic approach as the continuation of the event tree is useful for checking the comparability of both methods or in a case when the probability approach does not yield reliable results. As mentioned in Section 2, the high risk in tunnels is limited to events with low likelihood and large consequences. The approach proposed by Persson [16] has complemented the QRA approach promoted by the OECD/PIARC, QRAM model, widely used in EU countries as a consequence of EU directive EU 2004/54/EC.

Most of the methodologies—Austrian tunnel risk model TuRisMo, the Dutch QRA tunnels, the French specific hazard identification and the Italian risk analysis for road tunnels that consider the transportation of dangerous goods—include the use of QRAM software. Consequence models are the key elements in the risk estimation. All fire, explosion and smoke dispersion models used in QRAM are based on simple lumped models and empirical equations in one-dimensional space. Therefore, the computation of physical phenomena is fast and appropriate for multiple risk calculations, but the accuracy of the consequence is questionable. The higher the complexity of the fire scenario, the greater is the uncertainty of the results [29].

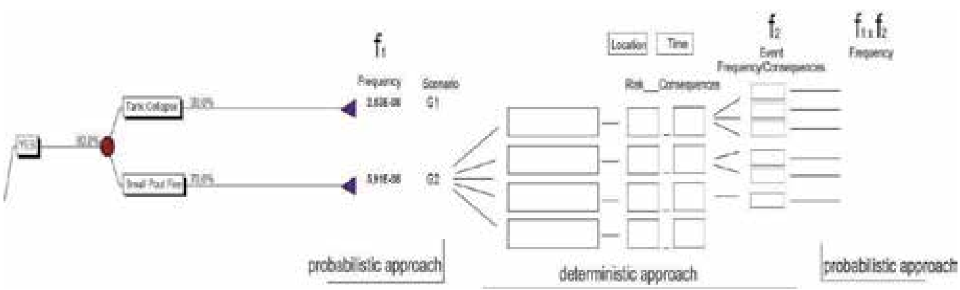


Figure 5.
Passage from a deterministic to a probability risk analysis method.

The calculation of consequences with a CFD program is performed for the same scenarios as Persson [16], including the same evacuation concept, and the number of fatalities is calculated. Three main scenarios are analysed, G2, G5 and G8, which represent three different fire sources (**Figure 6**).

Findings observing CFD results are important because they show some undetectable phenomena. The simulation of a 17 MW fire (scenario G2) shows that the use of longitudinal ventilation, according to the emergency ventilation plan, is worse than without ventilation for the whole evacuation time. The reason is hidden in the smoke movement dynamics. During natural ventilation the smoke layer is kept stratified under the celling, and evacuation is possible through the bottom layer. The start of the longitudinal ventilation after 10 minutes causes the formation of vortices that break down the stratification and fill up the tunnel with smoke. It takes several minutes for jet fans to clean the evacuation side of the tunnel from smoke.

This transition process is usually not correctly covered by simple 1D models as presented in Persson [16].

5.1 Risk levels

Based on the calculated individual risk frequencies, the collective risk is computed. Integrating the probability of death for each event over the number of people in the tunnel represents the number of fatalities by a given event. **Figure 7** illustrates the modelled risk level for a gasoline spill in the F-N diagram.

Each scenario frequency obtained from the event tree is multiplied by the calculated number of fatalities from the CFD simulation results. The risk level is calculated as the sum of the fatality frequency per year for the analysed accidents. This is the potential loss of life risk (PLL) per year for scenarios that endanger a calculated number of persons in **Table 5**. Further, the cumulative fatality frequency is calculated, and the F-N curve is plotted in **Figure 7**.

Two F-N curves in **Figure 7** are compared in order to understand the applicability and advantage of simulating fire scenarios with CFD. The boundary of risk is

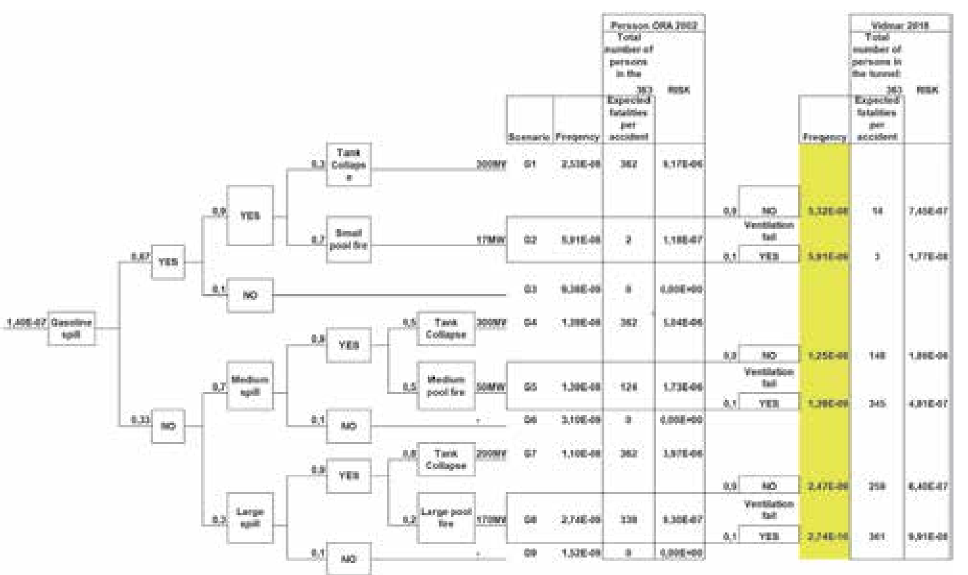


Figure 6.
Event tree for gasoline spill.

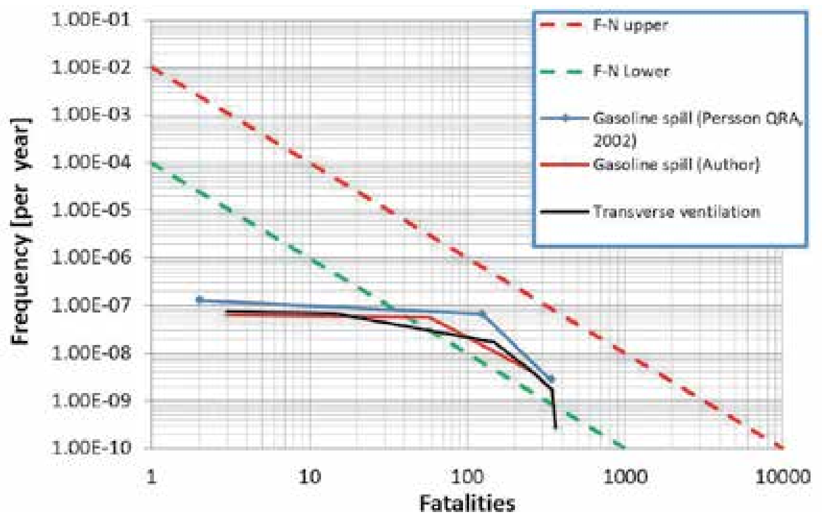


Figure 7.
Collective risk level for gasoline spill in a tunnel.

Gasoline spill (author)			
Fatalities [per accident]	**PLL risk (fatalities) [per year]**	**Event frequency [per year]**	**Cumulative fatality frequency [per year]**
0	$0.00E + 00$	$1.25E - 08$	$7.58E - 08$
3	$1.77E - 08$	$5.91E - 09$	$6.32E - 08$
57	$3.03E - 06$	$5.32E - 08$	$5.73E - 08$
258	$6.37E - 07$	$2.47E - 09$	$4.14E - 09$
345	$4.81E - 07$	$1.39E - 09$	$1.67E - 09$
361	$9.91E - 08$	$2.74E - 10$	$2.74E - 10$

Table 5.
Cumulative risk for gasoline spill accident.

defined with a risk acceptance criteria. Since the risk criteria vary from country to country, it is difficult to generalise and say whether the risks are acceptable or not. Author Trbojevic [30] and others have emphasised the individual risk criteria based on the existing national standards and guidelines. The harmonisation of risk acceptance criteria for the transport of dangerous goods is proposed in the final report of the DG-MOVE project [31]. The upper and lower risk used is (**Table 6**):

Parameters for societal risk criteria	Value	Denomination
F_{upper} (dotted line between ALARP and intolerable)	$1 \cdot 10^{-2}$	Fatalities/year
F_{lower} (dotted line between ALARP and negligible)	$1 \cdot 10^{-4}$	Fatalities/year

Table 6.
Limits for societal risk.

The F-N curve modelled by Persson [16] is very close to the curve modelled in this paper by the authors. Although both risk curves are within the ALARP area, the author's is closer to the low-risk criteria. In both cases no additional risk control options (ROCs) are needed. In case one, if the risk curve would exceed the upper risk criteria and therefore impose the ROCs, a precise calculation of consequences could reduce the actual risk. **Figure 7** also shows the F-N curve for the same scenarios (G2, G5, G8) using transverse ventilation during a fire. All simulations are done on a relatively short tunnel, and the F-N curve shows no significant difference between the two ventilation systems. The risk curve drop for a transfer ventilation indicates the advantage of this ventilation for long tunnels.

Risk assessment of a road tunnel is normally divided into risks arisen from traffic density, influenced by environmental and infrastructural elements, fire scenarios in a tunnel considering tunnel equipment and evacuation/rescue plans. The overall risk is influenced by all these elements. However, the most unknown remains the smoke dynamics under the influence of a tunnel ventilation system, pressure difference between cross passages and pressure difference between portals. The use of empirical fire models and one-dimensional flow movement models is appropriate, under the authors' consideration, for the verification of ventilation plans, but is not reliable enough for the estimation of individual risks.

Risk assessment is normally a continuous process observed on daily, weekly or seasonal intervals, to assure the acceptance of a tunnel's operational risk. In practice risk assessments have been conducted once after 2004 for all EU operating tunnels on Trans-European Network (TEN) and for every new building to fulfil legal requirements. After that these same tunnels have updated their risk assessments mainly after some reconstruction or traffic regime changes. The increased traffic density and the increased share of dangerous goods on HGV are not assessed after a decade since QRA implementation. Although the CFD fire simulation takes more time to be processed than simple fire models, they could provide the assessor consolidated and reliable results on fire and smoke dynamics, which is mandatory for evaluating the magnitude of consequences for human lives. Because the recent history of QRA for tunnels shows us that assessments have been conducted once for the majority of tunnels, there is a strong justification to perform fire dynamics analysis with the most reliable possible approach. In this case the presented paper promotes the approach for this part of the QRA process that is fully compatible with existing approaches like QRAM or other methods.

6. Conclusion

A complexity of fire scenarios with different tunnel ventilations and fire forces is presented in the paper. Despite the long computational time required to process CFD simulation of fire in a tunnel, the process is worth the time and necessary for evaluating the most likely consequences to users during an accident. The reliability of CFD results is significant, and the validation of the fire model is presented compared with experimental results. This is a mandatory process of a model preparation before the actual scenario simulations. A deep focus on CFD models is omitted from the paper although a large number of referenced authors have applied FDS to tunnel simulation. The processing of results is further presented in the paper. Several authors, referenced during the discussion, never used CFD results to assess the risk to individuals, including during evacuation. The risk is here presented ranging from simulation results to risk levels from low to extreme risk, depending on temperature and smoke concentration at different tunnel heights. According to human resistance to high temperature and smoke concentration, the exposure risk is evaluated and presented in the number of fatalities per exposure time. The overall risk of a scenario is presented for natural, longitudinal and transverse ventilation.

The use of CFD programs in fire analysis is not new and has been widely used for more than a decade and has become a powerful tool for deep consequence analysis. The risk assessments of fire scenarios, on the other hand, still use a faster computational method. This is understandable where the risk is continuously assessed, but for tunnels with an unchanged geometry and ventilation systems, it is done but once. The most recognised representation of a societal risk is with a risk matrix, or, better, risk curves, as used in this paper. The methodology regarding how to link the calculated fire dynamics variables to consequences for human lives is explained, as well as, further, the use of these consequences to quantitatively determine the risk for users. Although the process for CFD calculation is time demanding, the author believes that taking such time is important, as it provides more reliable results and better support for the decision-making in the selection of effective risk control options.

The new improvement for the future risk assessments in tunnel would be the implementation of new fuels in the automotive technology either pressurised gas like LPG or hydrogen and LNG. Similarly, a larger introduction of hybrid and electric vehicles would influence the change in the concept of tunnel safety.

Author details

Peter Vidmar
Faculty of Maritime Studies and Transportation, University of Ljubljana, Portorož, Slovenija

*Address all correspondence to: peter.vidmar@fpp.uni-lj.si

References

[1] Nývlt O, Prívara S. Probabilistic risk assessment of highway tunnels. Tunnelling and Underground Space Technology. 2011;**26**(1):71-82

[2] Ntzeremes P, Kirytopoulos K. Applying a stochastic-based approach for developing a quantitative risk assessment method on the fire safety of underground road tunnels. Tunnelling and Underground Space Technology. 2018;**81**:619-631

[3] Commission of the European Communities. Directive of the European Parliament and of the Council on Minimum Safety Requirements for Tunnels in the Trans-European Road Network. Brussels: Commission of the European Communities; 2004

[4] Cassini P, Hall R, Pons P. Transport of Dangerous Goods Through Road Tunnels Quantitative Risk Assessment Model-QRAM. User Guide (Version 3.61). Paris: OECD/PIARC/EU (CD-ROM; 2007

[5] Haack A. Current safety issues in traffic tunnels. Tunnelling and Underground Space Technology. 2002; **17**:117-127

[6] Guoa X, Zhang Q. Analytical solution, experimental data and CFD simulation for longitudinal tunnel fire ventilation. Tunnelling and Underground Space Technology. 2014; **42**:307-313

[7] Roh JS, Ryou HS, Parkb WH, Jang YJ. CFD simulation and assessment of life safety in a subway train fire. Tunnelling and Underground Space Technology. 2009;**24**(4):447-453

[8] Vidmar P, Petelin S. Methodology of using CFD-based risk assessment in road tunnels. Thermal Science. 2007; **11**(2). Available from: http://thermalscience.vinca.rs/pdfs/2007-2/14-vidmar.pdf

[9] Vidmar P, Petelin S. An analysis of a fire resulting from a traffic accident. Journal of Mechanical Engineering. 2003. ISSN 0039-2480;**49**:1-13

[10] Cheng LH, Ueng TH, Liu CW. Simulation of ventilation and fire in the underground facilities. Fire Safety Journal. 2001;**36**:597-619

[11] Jojo SML, Chow WK. Numerical studies on performance evaluation of tunnel ventilation safety systems. Tunnelling and Underground Space Technology. 2003;**18**:435-452

[12] Xiaoping G, Zhang Q. Analytical solution, experimental data and CFD simulation for longitudinal tunnel fire ventilation. Tunnelling and Underground Space Technology. 2014; **42**:307-313

[13] Anga CD, Rein G, Peiro J, Harrison R. Simulating longitudinal ventilation flows in long tunnels: Comparison of full CFD and multi-scale modelling approaches in FDS6. Tunnelling and Underground Space Technology. 2016;**52**:119-126

[14] PIARC. Technical Committee on Tunnel Operation, Fire and Smoke Control in Road Tunnels. France: PIARC; 2003

[15] Brussaard LA, Kruiskamp MM, Oude Essink MP. The Dutch Model for the Quantitative Risk Analyses of Road Tunnel. The Netherlands: Ministry of Transport; 2004

[16] Persson M. Quantitative Risk Analysis, Procedure for the Fire Evacuation of a Road Tunnel. Sweden, Lund: Department of Fire Safety Engineering, Lund University; 2002

[17] McGrattan K, Baum H, Rehm R, Hamins A, Forney GP, Floyd JE, et al. Fire Dynamics Simulator-Technical Reference Guide. Vol. 2009. USA: National Institute of Standard and Technology; 2009

[18] Sagaut P. Large Eddy Simulations for Incompressible Flows. 2nd ed. Berlin Heidelberg: Springer; 2002

[19] Lesieur M. Turbulence in Fluids. Netherlands: Kluwer Academic Publisher; 1997. ISBN: 0-7923-4415-4 (HB)

[20] Haack A. Fire protection in traffic tunnels: General and results of the EUREKA project. Tunnelling and Underground Space Technology. 1998; **13**(4):377-381

[21] Gann RG, Hall JR. Fire conditions for smoke toxicity measurement. Fire and Materials. 1994;**18**:193-199

[22] Drysdale D. An Introduction to Fire Dynamics. United Kingdom: John Wiley and Sons Ltd; 1998

[23] Memorial Trunnel Fire Ventilation Test Program. Central Artery/Tunnel Project. USA: Massachusetts Highway Department; 1996

[24] Weng M, Lu X, Liu F, Du C. Study on the critical velocity in a sloping tunnel fire under longitudinal ventilation. Applied Thermal Engineering. 2016;**94**(5): 422-434

[25] Woodburn PJ, Britter RE. CFD simulations of a tunnel fire. Fire Safety Journal. 1996;**16**:35-62

[26] Kirchsteiger C. On the use of probabilistic and deterministic methods in risk analysis. Journal of Loss Prevention in the Process Industries. 1999;**12**:399-419

[27] Pinto A. QRAM a qualitative occupational safety risk assessment model for the construction industry that incorporate uncertainties by the use of fuzzy sets. Safety Science. 2014;**63**:57-76

[28] Pribyl O, Pribyl P, Horak T. System for deterministic risk assessment in road tunnels. Procedia Engineering. 2017;**192**: 336-341

[29] Zhang X, Xu Z, Ni T, Peng J, Ran Q. Investigation on smoke temperature distribution in a double-deck tunnel fire with longitudinal ventilation and lateral smoke extraction. Case Studies in Thermal Engineering. 2018. In press, accepted manuscript, Available online 13 December 2018, Article 100375

[30] Trbojevic VM. Risk criteria in EU. In: ESREL'05, Poland. 2005. pp. 27-30

[31] Spoure J. Harmonised Risk Acceptance Criteria for Transport of Dangerous Goods. UK: DNV-GL Project Report; 2014

Chapter 5

Simulation Fidelity and Skill Learning during Helicopter Egress Training: The Role of Vision

Stefanie Dawn Martina, Gal Ziv, Elizabeth Sanli and Heather Carnahan

Abstract

This project aimed to evaluate the effects of ambient lighting during practice and performance of simulated helicopter escape sequences. Participants were randomized to one of the following groups to practice a standard helicopter underwater escape sequence: Light (with room lights on), Dark (with room lights off), or Graduated (in the light for the first half and then in the dark for the second half of the trials). Following practice, participants had a minimum of 30 min break, followed by retention testing in the dark and then in the light. Dependent measures included accuracy and movement time. Results indicated that participants performed more accurately during the dark retention trial than during the light retention trial. This could be due to increased arousal elicited by performance in the dark or, alternatively, may suggest that performance of helicopter escape sequences is not visually mediated. Based on findings, it appears that training in the light is suitable for potential performance in the dark.

Keywords: learning specificity, helicopter escape, simulation, HUET, training

1. Introduction

Safety training for high-risk industries and scenarios requires an approach that optimizes learning for enhanced skill learning and retention. An example is helicopter underwater escape training (HUET) for surviving a ditching over water. HUET is mandatory for offshore oil and gas employees and relevant military personnel. Currently, no universal training standard exists [1].

When a helicopter ditches in water, it typically inverts and sinks [2–4]. Crew and passengers often have less than 15 s of notice to make an underwater escape [5]. Not surprisingly, drowning has been identified as the leading cause of death following a ditching [6]. Disorientation and limited vision have been hypothesized as contributing to reduced survival [1, 7]. These factors are influenced by darkness, which has been linked with higher mortality rates during egress [1, 5]. Arguably, all egress occurs in low-light conditions. A nighttime helicopter ditching would obviously occur in dark conditions. However, regardless of time of day, numerous factors degrade light availability and consequently may impact visibility. For example, the inversion of the helicopter directs windows away from daylight and transmissivity of light through water is much less than light through air. As the helicopter sinks, light penetrance degrades. Indeed, at 35 feet of sea water, approximately 20% of light penetrates clear ocean water [8]. Debris presence [9] and water turbidity [8, 9] further impact light attenuation. Even at shallow depths with bright sunlight, very high turbidity can degrade visibility to less than 1 foot of distance [8]. Presumably, darkness would augment challenges that are exacerbated by poor visibility such as finding exits and getting oriented to the water's surface, thereby impacting survival. Research has shown that night flying is associated with reduced survival rates [1, 5]. One study reported that survival rates for a nighttime and daytime crash were 41 and 77%, respectively. Limited vision during egress was hypothesized as contributing to the reduced survival rate at night [1]. To mitigate this, emergency exit lighting has been incorporated in helicopter design, known as helicopter emergency escape lighting (HEEL). Some studies have demonstrated reduced escape times with HEEL in the laboratory setting [9–12]. However, the effectiveness of HEEL remains a concern, as there is some evidence to suggest that lights may not be detectable when seated by the aisle even with bright ambient lighting conditions [9].

To help prepare for emergency egress, many military organizations and industries have mandated that relevant personnel complete HUET. Since no universal training standard or assessment standard exists [13], whether trainees practice egress in low-light conditions will vary based on the best practices of individual training facilities. Limited research exists on optimal training curricula to improve performance and survivability. The principle of learning specificity states that practice is most effective when it closely matches actual performance conditions [14]. Skill learning is contingent upon the development of a sensorimotor plan that is sensitive to sensory information available during practice [14–16]. According to these principles, helicopter egress practice should be conducted in low-light conditions to optimize learning.

The 2009 Cougar Flight 491 helicopter crash off the Newfoundland, Canada coast prompted an increased focus on identifying and mitigating safety threats to helicopter night flying. Following the accident, the Commissioner's report recommended the restriction of night flying until adequate safety improvements were made [17]. A ban on night flights in the province has remained in effect. Another recommendation made was increased simulation fidelity of training. Simulation fidelity refers to "the degree of faithfulness between entities" [18]. The similarities between entities, or conditions, govern the degree of learning transfer [19, 20]. A high degree of simulation fidelity may be particularly important for optimizing learning when training for high-stress scenarios [1, 18, 21].

Although it was required that pilots demonstrate successful ditching during night flights, no attention has been given to the ability of passengers to demonstrate the ability to escape during low- or no-light conditions or to the fidelity of HUET to prepare for these conditions. Limited nighttime ditching training was identified as a potential factor contributing to the reduced survival rate [1]. Given the challenge of limited visibility during escape, it is plausible that training in dark conditions may be beneficial to learning and performance.

Since helicopter egress generally occurs in a low-light setting, the principle of learning specificity suggests that HUET would be most effective if also conducted in low- or no-light conditions. According to the principle of learning specificity, the most efficient sensory information available during acquisition dominates over other feedback sources and is utilized to develop a sensorimotor plan. Once developed, the sensorimotor plan remains sensitive to the optimal sensory information available during practice [14–16]. This principle was first demonstrated when participants who had practiced a manual aiming task with vision performed more poorly on transfer tests when vision was withdrawn, suggesting that vision is the dominant and preferred sensory source [22–24]. Accordingly, lack of visual feedback due to low ambient light levels during practice would result in performance decrements.

Ambient vision is thought not to be affected by low levels of light [25]. However, decreased light levels could reduce the acuity of visual feedback. This may consequently affect aspects of sensory feedback such as eye and head movement patterns. Changes in lighting can affect perception and object appearance, for example by shadow production [26]. It is plausible that low lighting may reduce visibility range, which could affect end-target sight or object recognition. For goal-directed movements where terminal visual feedback is imperative for movement calibration, performance would decline in low light conditions [27]. It is possible that learning may be similarly affected. Motor learning refers to the changes in internal processes that occur with practice or experience, which affects an individual's ability to execute a motor task. Motor learning depends on the integration and interpretation of sensory stimuli. Retention testing is the preferred method to assess learning, which involves evaluation of a trained task after some time interval. Performance is the observable production of a motor skill, which is influenced by transient factors such as fatigue, motivation, and affective state [25, 28–30]. Although related, it is important to note that performance and learning are distinct processes [25, 30].

To examine the role of visual feedback on learning specificity, studies have typically examined effects of manipulated visual feedback (e.g., by distortion or narrowing) or withdrawn vision during motor tasks. Proteau and colleagues had participants practice a manual aiming task, which required the movement of a stylus to an end target while mechanically perturbed and time constrained, in either a light or dark room [14, 22]. When participants trained in the dark and then performed a retention transfer test in the light, performance deteriorated. This demonstrated the impact of training condition for retention and transfer. Importantly, the end-target was always visible in the dark condition. Additionally, subjects performed over 1000 practice trials and were given knowledge of results following each trial. These conditions may not be generalizable to real-life contexts.

The present study aimed to evaluate the effects of lighting on practice and retention (i.e., learning) performance during helicopter egress sequences conducted in a simulator. Practice occurred either with all trials in the light (Light Group), all trials in the dark (Dark Group), or half of the trials in the light followed by half in the dark (Graduated Group). The Graduated group was intended to evaluate effects of progressive learning [31].

We hypothesized that the Dark Group would have superior retention performance in the dark compared to the Light Group, supporting the principle of learning specificity and the Graduated Group (that practiced in both the light and then the dark) would have similar performance to both the Light and Dark Groups in the respective retention tests.

2. Methods

2.1 Participants

Thirty-eight participants (20 females, 18 males; average age (SD): 31 (11) years, range: 19–58) were recruited from the local community. All participants had self-reported normal or correctable-to-normal vision and gave written consent. Procedures complied with the Declaration of Helsinki and ethics was approved by the Interdisciplinary Committee on Ethics in Human Research at Memorial University protocol 20180377-HK.

2.2 Task and apparatus

Experimental procedures were conducted at the Marine Institute's Offshore Safety and Survival Centre (MI-OSCC), Conception Bay South, Newfoundland, Canada. Trials were conducted in the Help Quest Helicopter Ditching Simulator (Virtual Marine, St. John's, NL) without use of the motion platform or simulated helicopter noise. The interior of the simulator replicates a Sikorsky S-92, which is used commonly for operational purposes internationally. For practical reasons, the simulator contains only four seats (two seats each by a starboard side window and two each by a port side window, forming two rows) compared to 19 seats in the actual S-92.

Practice trials were conducted in the front and rear port window seats and front starboard window seat since these seats had push-out window exits. Retention trials were conducted in the front port window seat. The front port seat was always in a crash attenuated position (stroked), which is low to the ground. A stroke seat collapses upon impact as part of an energy absorption system that is intended to prevent primarily spinal injuries after a crash. However, evidence suggests that egress from a stroked seat position is more challenging than from a normally positioned seat because the evacuee is now situated lower relative to the window (escape route) and is in an orientation where it is more difficult to generate sufficient force to push out the helicopter window for egress [13, 32].

Participants performed a standardized escape sequence (Appendix) during a simulated submerged helicopter ditching. The sequence included the following: taking off a headset; putting on a hood; putting on a scuba-type mask; crossing arms and tucking the head to brace for "impact"; putting a scuba-type regulator (mouthpiece attached to a compressed air-filled cylinder) in the mouth; preparing to exit by pushing the window; and unbuckling a four-point harness. Participants were prompted to execute sequence steps by the following verbal commands (given in the order listed): "ditching, ditching, ditching"; "brace, brace, brace"; and "impact, impact, impact". Cues were given at regular elapsed time intervals - the brace call was given 30–45 s after the ditching call (time interval based on completion of ditching steps), and the impact call was given 15 seconds after the brace call.

2.3 Procedures

Permuted block randomization was used to allocate participants into one of the following training groups: with room lights on for all trials (Light); with room lights off for all trials (Dark); or in the light for half of the trials and in the dark for the other half (Graduated).

The experiment consisted of a didactic session followed by simulator-based trials. The didactic session consisted of a 20-min pre-recorded training video in which a qualified and experienced instructor presented adapted material from the existing HUET course offered by the MI-OSSC. Information relevant to helicopter egress using Helicopter Underwater Escape Breathing Apparatus (HUEBA) was given, while other non-pertinent material was removed. Didactic sessions included up to four participants. HUET is regularly taught using group instruction format.

Participants performed simulator trials individually. Each participant was allotted one orientation trial with real-time feedback immediately preceding practice trials. The orientation trial was conducted in the rear starboard position, which was not used for practice or retention trials. No feedback was given once practice trials commenced.

Practice trials consisted of six total sequence executions, which is similar to the amount of practice performed during a HUET course. Participants rotated through each seat position (front and back port side; front starboard side) twice. Seat position order was counterbalanced. Practice trials took approximately 30 min to complete.

Following practice trials, participants were given approximately a 30- to 60-min break prior to retention testing. During this time, participants remained onsite and were permitted to engage in leisure activities of choice (e.g. reading, browsing on internet). For all participants, the retention tests consisted of one trial in the stroked seat in the dark followed by one trial in the light. Retention tests took approximately 10 min to complete. All practice and retention trials were recorded with a FLIR T430sc series infrared video camera that was able to capture video in dark conditions.

2.4 Dependent variables

Measures of performance included accuracy and movement time. Movement time was defined as the time in seconds (s) from the first action taken after the ditching command to when movement ceased. Participants were instructed to pause in the final position when he or she felt that the sequence was completed. Accuracy was measured with a checklist (refer to Appendix) where participants were awarded a point for every task in the sequence that was correctly performed. All subtasks had to be performed correctly and in the appropriate sequence to be awarded the point. The maximum possible score was seven. This checklist was developed through consultation with experienced HUET instructors at the OSSC and according to the training requirements of the Canadian Association of Petroleum Producers.

2.5 Analysis

Dependent measures during practice were analyzed by separate 3 (Group: Dark; Light; Graduated) X 3 (seat-position; front starboard; back port; front stroked port) Analyses of Variances (ANOVAs) with repeated measures on the seat-position factor.

Learning was evaluated by comparing practice trials conducted in the stroked seats, the dark retention test, and the light retention test. Data were analyzed in separate 3 (Group: Dark; Light; Graduated) X 3 (phase: practice trials in front stroked port seat; dark retention in stroked port seat; light retention in stroked port seat) ANOVAs with repeated measures on the phase factor.

3. Results

Data from 36 participants were included in the analysis. Two participants were excluded due to loss of performance data.

3.1 Practice accuracy

When the practice data were analyzed there was no main effect of Group ($F(2, 29) = 2.368$, $p = 0.112$, $\eta^2_p = 0.140$) or seat ($F(2, 58) = 0.865$, $p = 0.426$, $\eta^2_p = 0.029$). There was a significant Group by seat-position interaction ($F(4, 58) = 2.79$, $p = 0.035$, $\eta^2_p = 0.161$). Plots of each independent variable were used to assess interactions and inform post-hoc procedures. Post-hoc analysis was done by using three separate one-way ANOVAs for each seat positions. No significant effects were found (starboard ($F(2, 30) = 1.327$, $p = 0.280$, $\eta^2_p = 0.264$); back port

(F (2, 30) = 3.19, p = 0.055, η^2_p = 0.175); and front stroked port: (F (2, 29) = 1.758, p = 0.190, η^2_p = 0.108)).

3.2 Practice movement time

For practice, there were no statistically significant main effects for Group (F (2, 29) = 0.510, p = 0.606, η^2_p = 0.034) or seat position (F (2, 58) = 0.325, p = 0.722, η^2_p = 0.011), or for the interaction of these two factors (F (4, 58) = 0.580, p = 0.678, η^2_p = 0.038).

3.3 Retention accuracy

Retention analysis revealed a statistically significant main effect of phase (F (2, 58) = 6.012, p = 0.004, η^2_p = 0.172). Least Significance Difference (LSD) post hoc tests revealed that accuracy during the dark retention trial (mean = 4.9) was significantly better than during the practice trials (mean = 4.4; p = 0.006) and the light retention trial (mean = 4.6; p = 0.033, **Figure 1**). There was no significant main effect of Group (F (2, 29) = 1.168, p = 0.325, η^2_p = 0.075) or interaction effect of Group and phase (F (4, 58) = 0.819, p = 0.518, η^2_p = 0.053).

3.4 Retention movement time

Mauchly's test indicated that the assumption of sphericity has been violated for the main effect of trial (χ 2(2) = 7.067, p = 0.029); therefore, degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (ε = 0.920). A significant main effect of phase was found (F (1.839, 53.335) = 5.911, p = 0.006, η^2_p = 0.169). LSD post hoc tests indicated that participants took significantly longer during the practice trial (mean = 44.5 s) than during the light retention trial (mean = 39.2 s;

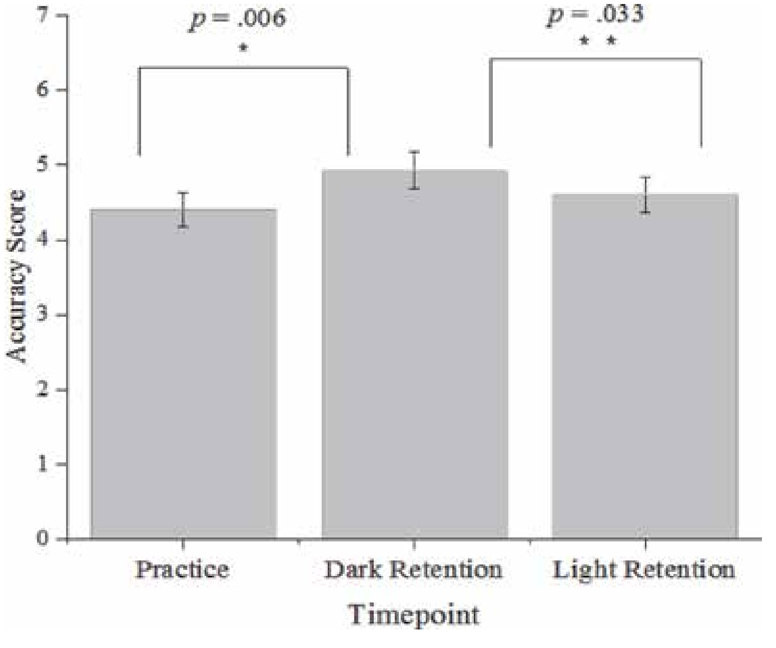


Figure 1.
Comparison of accuracy scores in the stroked seat during practice trials, dark retention test, and light retention tests. Standard error is represented by error bars.

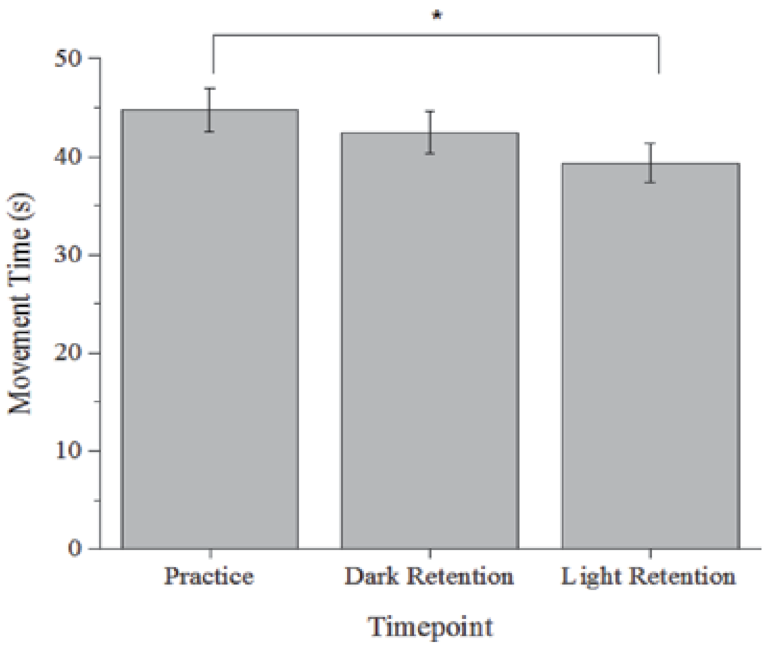


Figure 2.
Comparison of movement time during practice trials in the stroked seat, the dark retention test, and the light retention test. Standard error is represented by error bars.

$p = 0.001$; **Figure 2**). No significant main effect of Group ($F\ (2, 29) = 0.544$, $p = 0.586$, $\eta^2_p = 0.036$) or an interaction of phase and condition were found ($F\ (3.678, 53.335) = 0.819$, $p = 0.625$, $\eta^2_p = 0.042$).

4. Discussion

This is the first study aimed to evaluate performance of simulated helicopter escape sequences conducted in low light conditions. We hypothesized that in comparison to the Light Group, the Dark Group would demonstrate superior overall retention. We also hypothesized that the Graduated Group would perform equivalently to both the Light and Dark Groups in the respective retention tests. Results did not support our hypotheses. Performance during practice and retention did not differ significantly across groups, indicating that ambient lighting during practice did not affect performance. Based on our findings, training in the light appears to be appropriate for performance and learning of helicopter escape sequences that will be eventually performed in the dark. Findings may inform training standards and be relevant to other extreme environments domains, such as within the search and rescue and cave diving, where ambient light levels may vary and may impact performance. However, it is possible that the task was too easy and that under more ecologically valid conditions (e.g., performing in a mockup helicopter that is being dropped into a pool) that are accompanied with increased anxiety, results would have been different.

Interestingly, all participants performed more accurately during the dark retention trial than during the light retention trial or during the practice trials conducted in the stroked seat. However, movement times were significantly shorter during the light retention trial. This is indicative of a speed-accuracy trade-off. It is possible that the dark retention trial conditions promoted more optimal arousal than the light retention trial conditions. The Yerkes-Dodson law states that increased arousal will improve performance until optimal performance is achieved, after which point performance will decline as arousal further increases [33]. Attentional resources may be directed towards the task as self-awareness increases with anxiety. This may be detrimental to performance by disrupting automatic processes [34]; however, it can also benefit learning by inducing the allocation of more cognitive resources for task completion, which may attenuate aversive threat effects [35].

The principle of learning specificity has been primarily demonstrated in studies where participants have extensive practice. Evidence suggests that specificity effects are positively correlated with experience level, and thus are predominantly seen after the sensorimotor plan for a skill has been engrained and is automated [22, 23, 36, 37]. Participants in this study had either limited or no HUET experience. It is possible that experts, while outperforming novices, would experience performance decrements if escape occurred in the dark, but training had previously been conducted in the light. Another explanation may be that helicopter escape is not visually mediated. Lastly, it is possible that it is relatively easy to perform the set of required actions on a dry simulator with no motion and hence the lighting conditions did not affect performance.

It is important to discuss the meaning of the accuracy values. Mean accuracy score during the dark retention test was 4.9 (out of possible 7) but is this considered good performance? This is hard to answer directly as it is possible that on one hand, failure to properly execute two steps may still allow for helicopter egress whereas, on the other hand, it may prevent egress depending on what steps are involved. For example, if one mistakenly releases his/her safety harness before pushing out the window, the latter may not be possible. This is because once the safety harness is released, pushing the window while submerged will only lead to the being pushed away from the window. In other words, once the harness is released, the passenger may not have the necessary support or leverage to push out the window. If that happens, egress may not be possible. The passenger may need to egress through a different window that was opened by another passenger. Doing so would likely promote disorientation and, in the extremely high stress scenario, may not be realistically possible. Hence, we suggest that instructors may need to decide whether some steps in the sequence of actions are more critical than others. If so, in the limited time available for training, it may be prudent to emphasize critical steps and ensure accuracy and appropriate sequence of execution.

Two limitations of this study are noteworthy. First, as mentioned before, the conditions were relatively easy and did not fully mimic an actual ditching experience. It is anticipated that the inclusion of more naturalistic conditions such as noise and motion from the helicopter, heat stress and discomfort from the flight suits, and, perhaps most importantly, escape while underwater would affect the ability to learn and retain the required skills. Second, the retention period in this study was only 30 min. A longer retention period would have been more ecologically valid as passengers are certified in this procedure every 3–4 years, depending on the jurisdiction. Hence, it would be important to examine the ability to retain the egress skills in a longitudinal study.

5. Conclusion

Our results suggest that the practice of helicopter escape sequences in the light may be sufficient for performance during virtual reality simulation in the dark. It is interesting to note, however, that the average accuracy across groups for the dark and light retention tests were both 5 points out of a maximum of 7 points. Arguably, any score less than 7 could have severe consequences in the real-world. Higher fidelity studies would help to better characterize optimal practice conditions to further inform training standards.

Appendix: accuracy assessment

Simulated Helicopter Escape Sequence Checklist (max score = 7 points)
Call 1: Ditching

1. Performed actions to get watertight
    - Took off headset
    - Put on hood (positioned correctly and tucked all hair inside hood)
    - Pulled up hood zipper
    - Put on mask (positioned correctly and placed skit of mask below hood)

Call 2: Brace

2. Assumed brace position
    - Crossed arms with fingers under shoulder harness (placed arm closest to exit on top and hooked HUEBA hose with thumb on hand farthest from the window)
    - Placed feet flat on the floor and clear of seats

Call 3: Impact

3. Gazed out window and maintained gaze throughout subsequent steps
4. Opened window
5. Placed hand or elbow closest to exit on window corner and maintained contact throughout subsequent steps
6. Deployed HUEBA
    - Removed dust cap from regulator with appropriate hand
    - Placed HUEBA in mouth
7. Released harness

Author details

Stefanie Dawn Martina[1*], Gal Ziv[2,3], Elizabeth Sanli[4] and Heather Carnahan[1,3]

1 School of Human Kinetics and Recreation, Memorial University, St. John's, NL, Canada

2 Academic College at Wingate, Wingate Institute, Netanya, Israel

3 School of Maritime Studies, Marine Institute, Memorial University, St. John's, NL, Canada

4 Offshore Safety and Survival Centre, Marine Institute, Memorial University, St. John's, NL, Canada

*Address all correspondence to: sdmartina@mun.ca

References

[1] Taber MJ. Simulation fidelity and contextual interference in helicopter underwater egress training: An analysis of training and retention of egress skills. Safety Science. 2014;**62**:271-278

[2] Brooks CJ, MacDonald CV, Donati L, Taber MJ. Civilian helicopter accidents into water: Analysis of 46 cases, 1979–2006. Aviation, Space, and Environmental Medicine. 2008;**79**(10):935-940

[3] Ryack BL, Luria SM, Smith PF. Surviving helicopter crashes at sea: A review of studies of underwater egress for helicopters. Aviation, Space, and Environmental Medicine. 1986;**57**:603-609

[4] Taber M, McCabe J. Helicopter ditching: Time of crash and survivability. Journal of Safety Research. 2006;**34**:5-10

[5] Brooks CJ, MacDonald CV, Baker SP, Shanahan DF, Haaland WL. Helicopter crashes into water: Warning time, final position, and other factors affecting survival. Aviation, Space, and Environmental Medicine. 2014;**85**(4):440-444

[6] Coleshaw SR. Minimum performance requirements for helicopter underwater breathing systems. Journal of Ocean Technology. 2012;**7**(3):60-73

[7] Cheung B, Hofner K, Brooks CJ, Gibbs P. Underwater disorientation as induced by two helicopter ditching devices. Aviation, Space, and Environmental Medicine. 2000;**71**(9):879-888

[8] Butler F. Diving and hyperbaric ophthalmology. Survey of Ophthalmology. 1995;**39**(5):347-366

[9] O'Neill BD, Kozey JW, Brooks CJ. Underwater detectability of a lighting system on a helicopter escape exit. Aviation, Space, and Environmental Medicine. 2004;**75**:526-530

[10] Allan JR. An illuminated guide bar as an aid for underwater escape from helicopters. RAF Institute of Aviation Medicine Report; 1988. p. 566

[11] Luria SM, Ryack BL, Neri DF. Desirable Characteristics of Underwater Lights for Helicopter Escape Hatches. Report No: 990. Groton, CT: Naval Submarine Medical Research Laboratory; 1982. 34p

[12] Ryack BL, Smith PF, Champlin SM, Noddin EM. The Effectiveness of Escape Hatch Illumination as an aid to Egress from a Submerged Helicopter: Final Report. Report No: 857. Groton, CT: Naval Submarine Medical Research Laboratory; 1977. 22p

[13] Taber MJ, Mcgarr GW. Confidence in future helicopter underwater egress performance: An examination of training standards. Safety Science. 2013;**60**:169-175

[14] Proteau L, Marteniuk RG, Lévesque L. A sensorimotor basis for motor learning: Evidence indicating specificity of practice. The Quarterly Journal of Experimental Psychology, Section A. 1992;**44**(3):557-575

[15] Elliott D, Chua R, Pollock BJ, Lyons J. Optimizing the use of vision in manual aiming: The role of practice. The Quarterly Journal of Experimental Psychology, Section A. 1995;**48**(1):72-83

[16] Mackrous I, Proteau L. Specificity of practice results from differences in movement planning strategies. Experimental Brain Research. 2007;**183**:181-193

[17] Wells R. Canada-Newfoundland and Labrador Offshore Helicopter Safety

Inquiry (Vol. 1). St. John's, NL: Canada-Newfoundland and Labrador Offshore Petroleum Board; 2010. 324p

[18] Grierson LE. Information processing, specificity of practice, and the transfer of learning: Considerations for reconsidering fidelity. Advances in Health Sciences Education. 2014;**19**(2): 281-289

[19] Barnett ML, Ross D, Schmidt RA, Todd B. Motor skills learning and the specificity of training principle. Research Quarterly of the American Association for Health, Physical Education, and Recreation. 1973;**44**(4): 440-447

[20] Henry FM. Specificity vs. generality in learning motor skill. In: Brown RC Jr, Kenyon GS, editors. Classical Studies in Physical Activity. Englewood Cliffs, NJ: Prentice-Hall; 1968. pp. 328-331

[21] Gratch J, Marsella S. Fight the way you train: The role and limits of emotions in training for combat. The Brown Journal of World Affairs. 2003; **10**(1):63-75

[22] Proteau L, Marteniuk RG, Girouard Y, Dugas C. On the type of information used to control and learn an aiming movement after moderate and extensive training. Human Movement Science. 1987;**6**:181-199

[23] Proteau L. Visual afferent information dominates other sources of afferent information during mixed practice of a video-aiming task. Experimental Brain Research. 2005; **161**(4):441-456

[24] Proteau L, Carnahan H. What causes specificity of practice in a manual aiming movement: Vision dominance or transformation errors? Journal of Motor Behavior. 2001;**33**(3):226-234

[25] Schmidt RA, Wrisberg CA. Motor Learning and Performance: A Situation- Based Learning Approach. 4th ed. Champaign, IL: Human Kinetics; 2008. 395p

[26] Hietanen JK, Perrett DI, Oram MW, Benson PJ, Dittrich WH. The effects of lighting conditions on responses of cells selective for face views in the macaque temporal cortex. Experimental Brain Research. 1992;**89**(1):157-171

[27] Behan M, Wilson MR. State anxiety and visual attention: The role of the quiet eye period in aiming to a far target. Journal of Sports Sciences. 2008; **26**:207-215

[28] Issurin V. Training transfer: Scientific background and insights for practical application. Sports Medicine. 2013;**43**(8):675-694

[29] Movahedi A, Sheikh M, Bagherzadeh F, Hemayattalab R, Ashayeri H. A practice-specificity-based model of arousal for achieving peak performance. Journal of Motor Behavior. 2007;**39**(6):457-462

[30] Schmidt RA, Lee TD. Motor Control and Learning: A Behavioral Emphasis. 4th ed. Champaign, IL: Human Kinetics; 2004. 537p

[31] Guadagnoli MA, Lee TD. Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning. Journal of Motor Behavior. 2004;**36**(2):212-224

[32] Taber MJ, Sweeney D, Bishop N, Boute R. Factor effecting the capability to jettison an S92 push-out window. International Journal of Industrial Ergonomics. 2017;**58**:79-89

[33] Yerkes RM, Dodson JD. The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative Neurology and Psychology. 1908;**18**(5):459-482

[34] Eysenck MW, Calvo MG. Anxiety and performance: The processing

efficiency theory. Cognition & Emotion. 1992;**6**(6):409-434

[35] Eysenck MW, Derakshan N, Santos R, Calvo MG. Anxiety and cognitive performance: Attentional control theory. Emotion. 2007;**7**(2): 336-353

[36] Krigolson OE, Tremblay L. The amount of practice really matters: Specificity of practice may be valid only after sufficient practice. Research Quarterly for Exercise and Sport. 2009; **80**(9):197-204

[37] Tremblay L, Proteau L. Specificity of practice in a ball interception task. Canadian Journal of Experimental Psychology. 2001;**55**(3):207-218

Chapter 6

Scaling Accident Coping Strategies and Testing Coping Capability

Paul Smith

Abstract

Accidents are events that we do not want to happen. But they do. And present-day stresses in our complex society can evolve into future accidents, and potential disasters. Root causes range from poor maintenance at nuclear facilities, to effects amplified by climate change. The traditional paradigm used to account for accidents is made up of three parts. The first is to assess the risk of occurrence, then to judge if the assessed risks are acceptable compared to society's benefit, and ultimately to provide a generalised emergency service that will try to mitigate the consequential impact. Taking a more holistic and critical approach is to question and test if the preparedness, response and recovery capability is adequate. This represents a new paradigm for accident management, involving the need to quantitatively scale our accident and disaster coping strategies and capability. The scaling analysis needs to account for magnitude, time, rate and space.

Keywords: accident, disaster, society, risk, holistic, scaling, test, coping strategy, coping capability, preparedness, response, recovery

1. Introduction

The logic in this chapter began as a very rudimentary concept in the author's mind, a short time after the nuclear power plant accident at Fukushima Daiichi, on the north east coast of Japan in March 2011 [1]. I felt that we had to fundamentally improve not only the measures we apply to prevent severe man-made accidents, but to also question how we may improve our coping capability [2–16]. The aim being to wisely determine if a given coping strategy and civil emergency response strategy was actually sound and credibly doable [17–22]. If not, then to establish a more systematic [23, 24] and consistent process [25–27] for modelling civil emergency response that would identify practical improvements when and where needed, specifically in terms of the emergency preparedness, response and recovery tasks; progressing through civil emergency, see **Figure 1**.

Going back some 34 years to 1975, Harold C. Cochrane at the University of Colorado, produced a ground breaking study in the USA, looking at 'Natural Hazards and their Distributive Effects' [11]. Cochrane's work was also done in cooperation with Gilbert F. White and J. Eugene Haas [10]. More than any other, when I first read this work by Cochrane, it helped to formulate a more systematic and holistic approach for modelling civil emergency response [16, 23]. When I was descending into New York's JFK in 2014, I happened to have been reading Cochrane's paper, as well as the studies by White and J. Eugene Haas [10, 11]. As I looked out of the window, I saw the absolutely enormous expanse of man-made sprawl across

IntechOpen

New York's urban region. At that split second—some might say a *light-bulb moment*, having read Cochrane's work during my flight, then seeing the massive system of buildings and infrastructure, the distributive effect of a low pressure storm surge amplified by climate change resonated with me, see **Figures 2** and **3**.

For a particular dangerous hazard-shock scenario, the tasks to be carried out by the emergency service organisations (that is, society's civil protection personnel who have a duty to protect the public) may be assimilated with the effectiveness and ultimate success of their preparedness, response and recovery tasks and activities. From a modelling perspective—before, during and after the hazard-shock scenario, see **Figure 4**. In summary, I have tried to outline in this chapter the basis

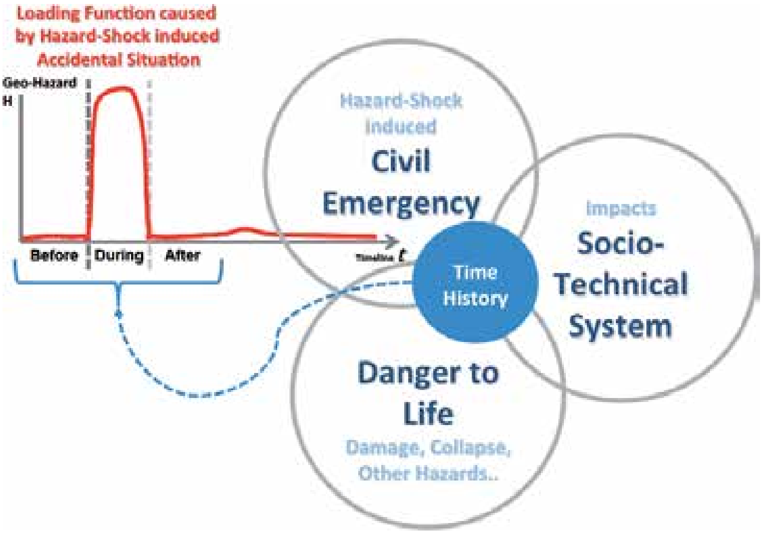


Figure 1.
Concept for temporal time history through a civil emergency.

Figure 2.
A modern-day urban city being a dense socio-technical system.

Figure 3.
Future global sea rise set to increase distributed scale of storms.

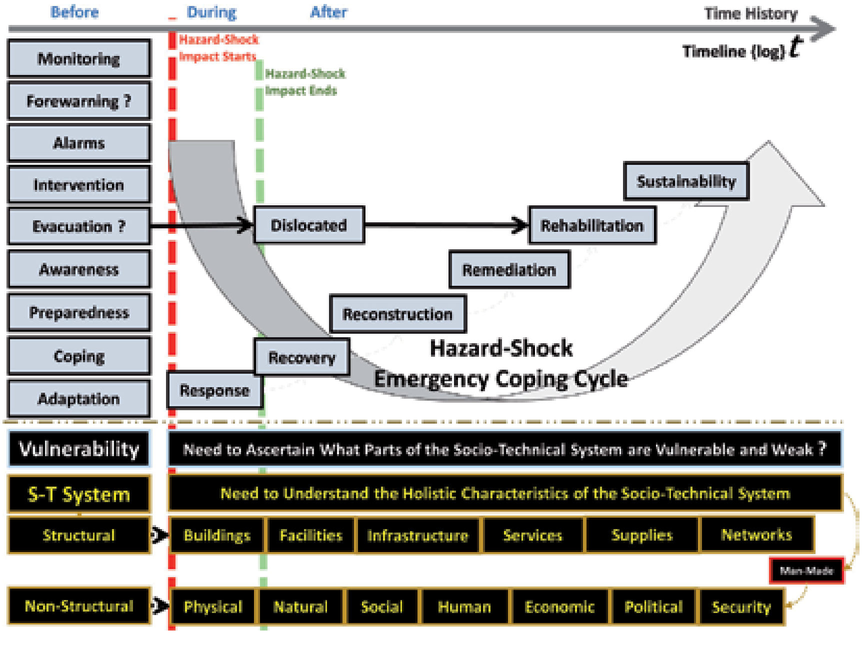


Figure 4.
Simple basis of emergency coping cycle in event of hazard-shock.

for a systematic and consistent process for modelling civil emergency response. The framework of this process encompasses:

- A background to survival and coping with future hazard-shock scenarios;

- Introducing seven types of generic hazard-shock scenarios for modelling;
- The duty for response to civil emergencies, including accidents and disasters;
- Subjective review of civil emergency coping capability;
- How to know the robustness of our socio-technical infrastructure;
- A new objective approach to quantify coping capability; and,
- The implications of climate change.

Applying this systematic process should help civil emergency duty organisations to verify and validate their accident and disaster coping strategies. The hierarchy of the process discussed in this chapter also enables a graded approach to be applied, from subjective qualification to a more rigorous objective quantification which uses a temporal coping capability analysis model.

2. Understanding the background

Accidents and disasters come in many forms. Conflicts of war, unintentional man-made accidents and natural disasters destroy the peace and regular stable order of society. Since the start of the new century at the 2000th year millennium, an upsurge of international terrorism became a harbinger of fear and anger (that still exists today), hurting innocent people and causing mass exodus of refugees.

Another profound problem has evolved as a stress on society since the industrial revolution; the release of gaseous carbon into the atmosphere by burning fossil fuels has given us global warming [13]. Now the impact of global warming has become a stark reality, whether experienced by extremely dangerous storm winds, flood inundation and rapid wildfires. Global warming can exacerbate accidents and disasters [5, 13, 15, 18]. During and after such dangerous scenarios, we all must try to cope and survive. We shall have to be prepared for more extreme magnitude and longer period hazard-shock scenarios, amplified by climate change. The future aftermath consequences initiated by seemingly 'natural' hazards will see larger areas affected, more severe to extreme forces, causing many lives to be lost, subsequently having increased government spending and insurance claims [10, 11]. It is therefore important to understand the severity of the hazard-shock scenario's time history and theoretically simulate what could happen and how, see **Figure 1**. In addition, we need to distinguish between the scientific basis of hazard-shock scenarios, compared to the practical demand placed on the civil emergency response duty organisation, as well as the strain taken by the response personnel and other volunteers *on-the-ground*.

When a major accident or disaster occurs, the public look to the duty emergency services, volunteer bodies, and government officials to take care of things. The presumption being that the relevant regional and national authorities will duly respond and cope with the dangerous situation. From a local community viewpoint, and those who live in the affected region, the public would normally wait until the emergency services arrive, telling them either to stay indoors, or to evacuate. But local communities may well have to cope by themselves without any additional help immediately forthcoming; into the future such a situation is likely to become a common practice with climate change.

In **Table 1** we introduce the concept for categorising the form of the hazard-shock scenario that the civil emergency responder's must face. In simple terms, seven types of generic hazard-shock scenario may be identified (**Table 1**):

- Regular;
- Serious;
- Overwhelming;
- Unpredictable;
- Sudden;
- Rapid; and,
- Disastrous.

In the United Kingdom a statutory Act of Parliament has been in place since 2004 which requires Category 1 responders to attend to civil emergencies under the Civil Contingencies Act (CCA) [7], and its regulations [8]. It is a requirement under the CCA to periodically assess the risk of emergencies occurring which affect or may affect a regional area. Reviewing and assuring the validity of a Category 1 responder's risk assessment should take place as often as is necessary to ensure that the preparedness for incident and emergency response is reasonably sound and will

Regular	Regular exposure from severe shock scenarios that necessitate mobilisation of coping strategies with response, and possibly recovery plans; the effect of the shock that exercises some of the coping strategies, response and possible recovery capability.
Serious	Serious exposure from severe to extreme shock scenarios that necessitate mobilisation of coping strategies with both response and recovery plans; the effect of the shock stressing the coping strategies, response and recovery capability.
Overwhelming	Overwhelming exposure from extreme to catastrophic shock scenarios that necessitate mobilisation of coping strategies with both response and recovery plans, but the effect of the shock is overwhelming, making coping success very poor.
Unpredictable	Unpredictable exposure from severe to possibly overwhelming shock scenarios that necessitate mobilisation of coping strategies with both response and recovery plans, the effect of the shock stressing the coping strategies, and may be overwhelming, making coping success range from probable to very poor.
Sudden	Sudden exposure from shock scenarios when forewarning is not possible, fundamentally limiting the effectiveness of coping strategies with both response and recovery plans due an inability to be forewarned, prepared and to mitigate the possible consequences.
Rapid	Rapid exposure from shock scenarios when the onset of the shock is so quick as to fundamentally limit the effectiveness of coping strategies with both response and recovery plans due an inability to have time for preparation and mitigation of the possible consequences.
Disastrous	Disastrous exposure from shock scenarios giving catastrophic effects of mass destruction, loss of life and/or environmental devastation, far beyond what is possible to respond to or recover from, whatever coping strategies and capability may be available.

Table 1.
Generic categories of societal hazard-shock scenarios.

be essentially successful against its business continuity plans, as well as complying with CCA duties described in the Act and Regulations [7, 8].

It is generally accepted that responders will need to adopt a structured and systematic risk assessment process that guides the requirements for incident and emergency response. The intention being to achieve a sound and well organised response in the event accidents and disasters jeopardise the safety and well-being of the public. The risk from civil emergencies is usually assessed by standardised risk assessment [28], merged with long standing experience of responding to accidents and disasters [10, 11, 16–18, 21, 22, 29], as summarised below:

- **Contextualisation.** Identify stakeholders, process evaluation criteria and the principles to be used during the risk identification. Describe and understand the characteristics of the area (e.g. social, environmental, infrastructure and hazardous-substance sites).

- **Identification of the hazards.** For the range of hazard-shocks identified, to apply an allocation scheme for mobilisation across the Category 1 responders and their particular operational remit in the regional areas.

- **Risk analysis.** The principal responders for each hazard-shock should consider the risk likelihood, but also the time and spatial conditions of the hazard-shock's impact relative to the public at risk.

- **Risk evaluation.** The collective risk profile needs to be collated in terms of the likelihood and impact assessments for each hazard-shock, encompassing the range of hazard-shock scenarios that are believed to be of concern. Evaluating the significance of the hazard's impact is important in terms of the necessary preparedness and resources that will be needed to successfully respond and cope with any unfolding accidents or disaster.

- **Risk treatment.** Responding to hazard-shocks needs to be prioritised for action with the necessary risk reduction measures. This also means that there should be an awareness of the potential limitations and gaps in responder's coping capability and capacity. The awareness should be realistic and practical as to what can, and cannot be done.

- **Monitor and review.** Irrespective of the commitment and effort afforded to incident and emergency response plans, the analyses and modelling work done to direct the plans will retain some degree of theoretical simplifications and assumptions. Surveillance and monitoring of actual hands-on exercises provides insight and practical awareness that can then be used for continuous improvement, adjusting for incorrect initial assumptions, together with limited or inadequate coping capability issues.

The basic risk assessment approach [28] amounts to a pragmatic methodology that mates probability and consequence of an accident or disaster to gauge the imperative for defensive measures. Civil contingency responders are familiar with this approach, while unquestionably useful for immediate decision making at the time of initial attendance as well. However, previously derived regional and national risk registers can become outdated and invalid as time goes by, and this will likely be a significant issue with fast rate climate change on our socio-technical system.

In addition, basic risk assessment does not readily allow for verification or validation of preparedness, response, recovery and coping strategy plans. In order to further understand the coping demand and manning burden placed on the emergency services and their response management, it is advised that a broader holistic approach should be considered; as introduced in this chapter. It is also important to account for the temporal time history of the accident/disaster scenario, encompassing the period before, during and after the hazard-shock scenario has impacted the exposed region.

The generic risk from hazard-shocks, as well as accounting for underlying regional stresses and vulnerabilities, should therefore be holistically considered from a socio-technical system perspective and accounting for the temporal characteristics of the hazard-shock scenarios, as identified in **Table 1**. It will be important to model the stress and shock incubation period, on-set and rate of impact, including the form of the response needed and subsequent recovery from the aftermath. Other key factors to be considered are:

- The initiating events may be man-made, natural, or a mixed combination;
- Severe to extreme initiating events are intrinsically varied and difficult to exactly define;
- Apply a more holistic mindset for analysis of hazard-shocks impacting a socio-technical system that is sensitive to long-term stresses;
- Initiating events, hazards, threats, stresses or shocks—all can progress and eventually escalate to dangerous risk and the necessity for attendance of the emergency services as first responders; and,
- To wisely discriminate between safety and security issues that can arise.

It is important to apply a wider holistic thought process that is able to model the time-history response that tries to mitigate the consequential risk, while better define the temporal progression through a hazard-shock scenario. Independent of the actual technical form of the hazard-shock scenario, it is important to characterise the type and degree of burden that will be made on the Category 1 and 2 responders, commensurate with the UK's Civil Contingencies obligation in the UK [7, 8].

The spectrum of hazard-shock scenarios identified in **Table 1** may be used as a generic basis for periodic review, testing, assessment and possibly in-depth analysis of coping capability. In addition, it should be helpful to better understand the future demand that is likely to be placed on the civil emergency management and their response manning burden. Irrespective of whether the hazard-shock is caused by events like earthquake, wind, flood, etc. from the emergency responder's viewpoint there will generally be certain hazard-shock characteristics that will impose varying scales of demand on the emergency facilities and their manning, together with the speed of mobilisation and distances to be travelled by the responders. To holistically assess our society's socio-technical vulnerability, accounting for impact scenarios that will risk [7, 8, 21, 22], the following key factors should be considered:

- Human habitation and its demographics;
- Community health and welfare;
- Social stability and resilience;

- Protection of the environment;
- Damage, failure and inundation of infrastructure;
- Disruption and loss of critical supply chains, and,
- Loss of economic fluidity.

The engineered fabric that is intrinsic of our urban and rural infrastructure also has the potential to be vulnerable and trigger yet greater danger as a forcing hazard-shock scenario gets more severe and distributed across a broader area. Emergent and additional dangers shall arise when the region exposed has co-located industrial, petro-chemical and nuclear plants. In this circumstance, what might be judged as just a regular or serious hazard-shock scenario, could readily escalate to a more onerous overwhelming and unpredictable situation, as indicated in **Table 1**, simply because of the emergence of other man-made dangers. Like what happened at Fukushima Daiichi in 2011 [1]. With the more onerous hazard-shock scenarios, cascade and domino failures will occur, thereby increasing the scale of demand on the civil emergency response, as accidents occur and the expanding disaster escalates.

In the UK, another set of regulations applies to major industrial and petro-chemical plants, being the Control of Major Accident Hazards Regulations (or COMAH) [6]. This regulation aims to prevent major accidents involving dangerous substances and limit the consequences of incidents to people and the environment. The COMAH regulations are overseen by the UK's Health and Safety Executive (HSE) and the Environment Agency (EA) and apply to organisations or sites such as chemical production facilities, warehouses or distribution centres that handle or store large quantities of hazardous substances.

For large COMAH sites, known as top-tier sites, the regulations stipulate the need for Public Information Zones (or PIZs) around the facility and its site. This is because public communities will exist in the region of the COMAH site, whether by coincidental residences, or personnel and their families that depend on jobs working at the sites. The owner organisations that operate the facilities are obligated under COMAH to provide information about:

- The potentially dangerous substances and how they may affect the adjacent community in the event of a major accident at the facility;
- The policy and strategy for protecting the public, together with the particular safety measures that are established;
- How the public shall be warned and kept informed about a major incident and escalating accident situation; and,
- The recommended protective actions that the public and the local community should carry out to remain safe.

During an incident that requires the mobilisation of the emergency services and other civil contingency agencies, then it becomes imperative that the relevant COMAH owner-operators are also part of the response and recovery planning. In addition, the local/regional government, together with the wider residential public and local community volunteers must be engaged and coordinated with in order to successfully cope with every unfolding danger. The possible consequences for poor coping could be:

- Death and serious harm;
- The need for mass evacuation;
- Damage and collapse of property and buildings;
- Chemo-toxic pollution of the environment and water courses;
- Disruption and curtailment of business and economic prosperity; and,
- Possible collateral and cascading danger to other facilities and critical infrastructure beyond the original response zone.

Development of coping strategies with preparedness plans that form the basis for the coping strategy will also need to consider evolving stresses that will amplify a risk's consequence, including generic stress problems like:

- Increased population density;
- Challenges to economic prosperity;
- Uncontrolled pollution and waste;
- Lessening natural resources;
- Climate change effects and amplification of consequences;
- Reduced land caused by global sea rise;
- More devastating natural storms;
- Aggravated man-made threats—criminal and terrorist;
- Human conflict and wars;
- Public unrest, fear & mistrust; and,
- Lack of government and political clarity without a will to be proactive.

3. Subjective review of civil emergency coping capability

Here we will introduce a pragmatic civil emergency response review process that tests if the coping strategy and preparedness plan is realistic and viable. The intent of this coping review process is to subjectively assess an emergency response organisation's ability to cope with a wide range of future hazard-shock scenarios, impacting the socio-technical system and potentially causing a danger to life, see **Figure 1**. The range of generic societal hazard-shock scenarios advocated in this review process are introduced in **Table 1**, encompassing Regular, Serious, Overwhelming, Unpredictable, Sudden, Rapid and Disastrous; as introduced earlier in this chapter.

Broken out into three parts as a staged pathway, the review process is framed on three hierarchy levels—representing (i) generic, (ii) specific and (iii) regional investigation. This subjective approach is essentially an expert qualification of the overall coping capability through the complete civil emergency coping cycle (as depicted in **Figure 4**). The skeletal basis of the coping capability review and assessment process is provided here, setting out a benchmark template for staged discussion, involving particular review of stakeholder agreements and practical readiness for implementation.

It is likely that emergency responders should be able to assimilate their own past experience and future concerns for particular hazard-shocks that should fairly correlate with each generic category of the hazard-shock scenarios identified in **Table 1**. The key objective here is being to better understand what the responders can, and cannot do realistically, then to establish improvements with supplemental countermeasures.

3.1 Generic coping capability review mindset and scope

- This generic coping capability review should be of benefit to national governments, national medical organisations, leaders of the civil emergency services, insurance and tort liability-legal groups.

- Firstly, benchmark the basis of the coping capability review for the emergency response organisation by accounting for the complete range of generic categories of societal hazard-shock scenarios, as identified in **Table 1**. Effectively to 'stretch' the civil emergency coping strategy with its preparedness, response and recovery planning.

- The full scope of the coping capability review should investigate each category of societal hazard-shock scenario, one by one, starting from the 'Regular' (or normal) state, and then progressively investigating each category of societal hazard-shock scenarios, benchmarked with **Table 1**.

- Define the key review outputs needed to determine the organisation's overall coping capability for each societal hazard-shock scenario category from **Table 1**.

- Check that the review's resulting conclusions conform and comply with governmental and legal obligations, like with the UK's CCA and COMAH obligations [6–8] {while other countries will have similar civil emergency obligations}.

- Identify and include in the review process all relevant corporate and regional emergency response expertise.

- Identify and agree important interfaces between organisations and particular responder roles to participate in the coping capability review process.

- Agree other parties judged to be relevant for the benchmark hazard-shock scenarios who need to participate in the review process.

- Ensure the key stakeholders are engaged in the review process, while recognising direct and indirect organisations that will be part of the coping strategy and its preparedness (before), response(during) and recovery (after) the hazard-shock events.

- Formulate the benchmark hazard-shock scenarios that need to be progressed in the coping capability review, guided by **Table 1**.

- Clearly define the hazard-shock scenario time-history predictions to be appraised during the review, accounting for forcing magnitude, time of activities, rate of impact and sensitivity, and the spatial distribution across the affected area.

- Capture and document the generic review results of the civil emergency coping strategy, then preparedness, response and recovery plans.

- Review and consider the effectiveness and efficiency of the civil emergency coping strategy, preparedness, response and recovery plans to an exposed region.

- Establish the temporal hazard-shock scenario time-history demand placed on responders, starting from initial warning alarm, response mobilisation, through to final stand-down, while accounting for manning fatigue, tiredness and even mental post-event disorders.

- Provide prior coping capability review documentation packs to all participating groups and parties.

- Carry out the coping capability review by officially documenting all inputs and outputs, while making sure that no security protocols are undermined or bypassed.

3.2 Specific coping capability assessment and scope

- This specific coping capability review should be of benefit to local government, councils, police, fire service, ambulance, hospitals, critical infrastructure owner-operators, and the principal service and supply sector organisations—see **Figure 5**.

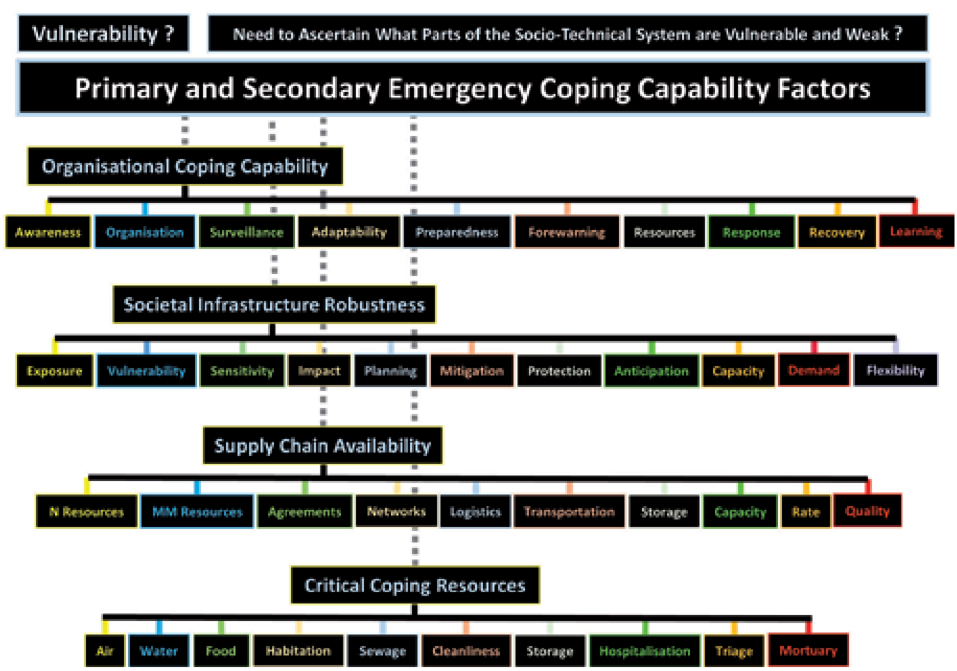


Figure 5.
Identifying important emergency coping capability factors.

- Establishing the key inputs and outputs that enable the specific coping capability assessment, and in readiness for validation of the regional response plans.
- Capture the basic holistic picture of the socio-technical components, including the structural and non-structural parts, including:
  - Physical fabric;
  - Buildings;
  - Facilities;
  - Infrastructure;
  - Networks;
  - Services;
  - Human demography;
  - Social structure;
  - Natural resources;
  - Economic and business-jobs; and,
  - Safety and security measures.
- Ensure the specific coping capability assessment process to take key account of impact the particular loss / emergent danger consequences, including:
  - Human life;
  - Community health and welfare;
  - Presence of industrial, petro-chemical and nuclear sites;
    i. Accounting for their respective dangerous substances, release and pathways;
  - Chemo-toxic releases;
  - Public evacuation;
  - Safe havens;
  - Societal reconstruction;
  - Contaminated land;
  - Remediation actions;

- ○ Rehabilitation practicalities;
- ○ Future sustainability (especially considering climate change and populous growth);
- ○ Social stability and resilience;
- ○ Protection of the environment;
- ○ Damage, failure and inundation of infrastructure;
- ○ Disruption and loss of critical supply chains; and,
- ○ Loss of economic fluidity.

- Establish specific definitions and criteria for regional socio-technical vulnerability, weaknesses, failure and loss parameters.

- Simplify shock/hazard/threat incident response coping capability into four mobilisation sectors, in order to cross-reference the fundamental organisational and socio-technical system, while the preliminary focus points (**Figures 5** and **6**) are advised to look at the:

  - ○ Organisational coping capability;
  - ○ Societal infrastructure robustness;

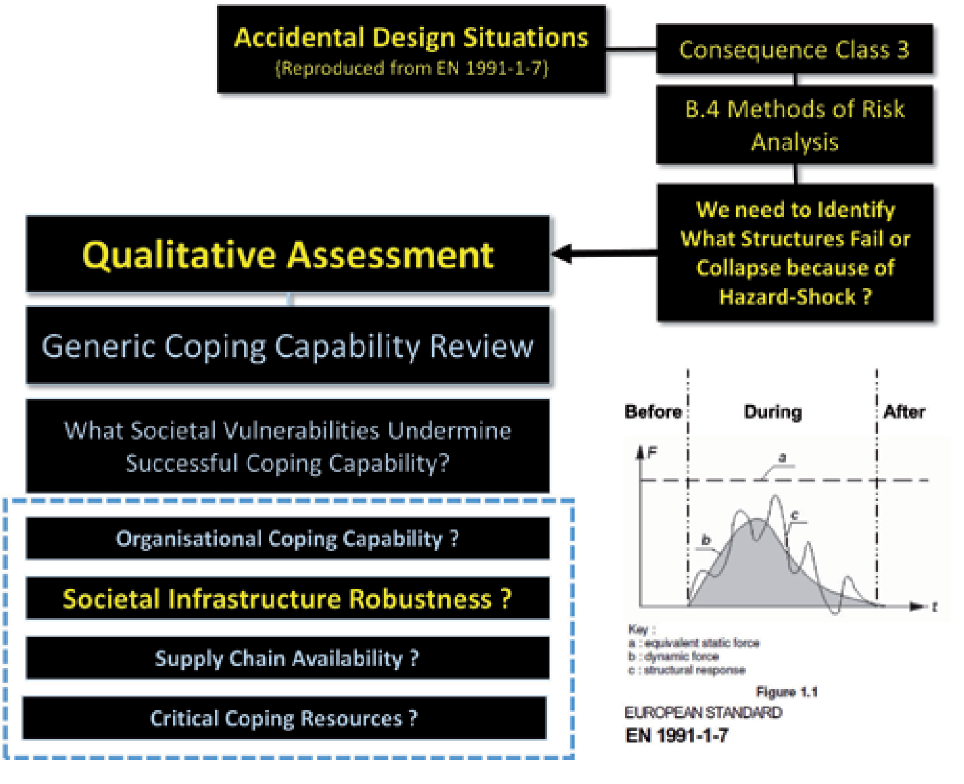


Figure 6.
Using existing structural (EN) standard to assess risk vulnerability.

    - Supply chain availability; and,
    - Civil contingency preparedness, response and recovery plans with the coping objectives.

- Progress through the temporal hazard-shock scenario timeline in terms of the emergency organisation's coping capability to perform and succeed with their civil contingency plans and objectives.

- To tally and interrelate the four fundamental organisational and socio-technical provision of the infrastructure, supply chains and critical coping resources needed for civil contingency preparedness, response and recovery plans/coping strategies, see **Figures 4** and **5**.

- Consider goodness of the specific coping capability, set against the specific standards and requirements that need to be achieved.

3.3 Regional (and local) validation of the coping capability

- This regional validation is essentially designed for actual 'hands-on' practice responders themselves, providing the benefit of their particular regional knowledge and expertise.

- Present to regional (and local) civil emergency response management and the official role holders the generic and specific coping capability assessment, referenced through the coping cycle in terms of the preparedness, response and recovery plans.

- Constructively engage with regional (and local) manager(s) and role holders, accounting for their regional (and local) feedback and advice, capturing any omissions, concerns or errors that may exist with the generic and specific coping strategy.

- Identify and collate recommended improvements to the emergency coping strategy and planning package, while also merging the regional feedback and advice—thereby gaining collective endorsement throughout the organisations and actors, at high generic level, specific technical and with the regional/local practitioners.

- Compile a Coping Capability Status Report for collective vision and feedback commentary.

- Revise the Coping Capability Status Report into a standardised report structure, including a live lessons learned section to enable future management improvement.

- Distribute the Coping Capability Status Report to all participants and indirect stakeholders.

- Regularly monitor and ascertain variations of significance that need to be addressed, while establishing a regular periodic review and Coping Capability Status Update.

4. Can the infrastructure stand up and functionally survive?

The scale of future hazard-shock born disasters is set to become much more onerous; in certain cases likely to be far beyond what our present existing fabric can tolerate and withstand. A region's basic resources must be adequate, fit for purpose and not diminish to zero during the hazard-shock's impact or its aftermath, otherwise the ability to cope be degraded and become ineffective. For example, it will be important to continue the provision of essential services and supplies in order to maintain the well-being and safety of the residents throughout the response and recovery phases, see **Figures 4** and **5**. Otherwise the residents shall have to be evacuated and relocated to a better position. However, evacuation may be extremely difficult to physically do, or not quick enough to accomplish within a safe time window, or simply impossible without clear and safe egress routes.

It is advised that a much more holistic approach is taken to analyse the significance of future emerging risks that can jeopardise our societal infrastructure, services, supplies and networks. Coping capability reviews are advised to consider the hazard-shock scenarios identified in **Table 1**. The coping capability review should encompass a much broader perspective of hazard-shock scenario consequences, including better understanding as to whether future hazard-shock scenarios cause cascade and domino failures of coping-critical buildings and infrastructure. In addition, there is a need to ascertain if safety-critical facilities and their adjacent emergency services can cope with ever larger scale distributed hazard-shocks amplified by climate change effects. The vulnerability of the socio-technical buildings and infrastructure needs to be better understood and recognised in the coping capability modelling, see **Figure 6**.

Different hazard-shock scenarios (as benchmarked in **Table 1**) will produce varying effects and consequences, dependent on the specific vulnerabilities that exist within the region's socio-technical system. Therefore, in the event that a severe to extreme natural hazard impacts a vulnerable region, exposing the societal fabric and residents to danger, the capability and capacity to (i) tolerate, (ii) withstand, (iii) absorb, or alternatively, (iv) break and fail to resist the hazard-shock's impact energy needs to be recognised, understood and assessed.

Let us now look for respected guidance that can help us to determine the robustness of our society's fabric and infrastructure. The European Standard EN 1991-1-7 becomes a useful guidance tool [30], see **Figure 6**. EN 1991-1-7 defines robustness as:

'*the ability of a structure to withstand events like fire, explosions, impact or the consequences of human error, without being damaged to an extent disproportionate to the original cause*'.

As advocated in EN1991-1-7 [30], the basic types of 'accident situations' that buildings need to be robust against includes:

- Natural hazards;
- Fire;
- Explosion;
- Impacts;
- Rail;

- Aircraft (with helicopter);
- Criminality;
- Terrorist threat;
- Other types of shocks and threats; as well as,
- Accounting for Inadequacies in the design and construction processes.

A wide distributed disaster together with man-made emergent dangers can put enormous pressure and demand on the local civil emergency responders, while severely stretching the effectiveness and efficiency of their coping strategy. This problem exists in regions exposed to very severe hazard-shocks that may also have industrial, petro-chemical and nuclear facilities sited there.

The accident at the Fukushima Daiichi nuclear power plant, in March 2011, demonstrated the need to explore scenarios in which external hazards that far exceed the original design basis of our as-built infrastructure. It became painfully apparent on the 11th March 2011 that we do not necessarily recognise or model what can happen beyond the design basis of our man-made infrastructure.

The fundamental problem here is that we could be ill prepared and inefficient in our attempt to have in place the appropriate civil emergency arrangements, while ultimately running the risk of not being able to effectively mitigate the consequences, nor cope with the longer-term recovery from the accident's aftermath. Due to the accident at Fukushima Daiichi nuclear power plant [1], the International Atomic Energy Agency (IAEA) decided to revise their guidance for nuclear power plant hazard-shock assessment. As a result of this effort, in 2017, the IAEA published an updated methodology for the vulnerability assessment of nuclear operating facilities subject to extreme external hazard-shock events, [31].

The types of specific hazard-shocks that would usually be identified for vulnerability assessment of an individual operating nuclear power plant using the IAEA's approach [31], are:

- Earthquake;
- High winds;
- Tornado;
- Abrasive windstorm;
- Hail;
- Lightning;
- Flood;
- Civil-ground instability;
- Extreme temperature;
- Volcanism;
- External fire;

- Explosion;
- Aircraft crash;
- Ship/barge impact;
- Collisions;
- Electromagnetic interference;
- Chemo-toxic release; and,
- Extra-terrestrial impact.

The philosophy used in [31] is to determine the strength of the hazards that could compromise safety, while trying to identify points of weakness in the man-made engineering. This methodology is intended to be used for existing nuclear power plants in their 'as-is' condition around the world, while the logic of the approach may readily be extended to encompass the regional infrastructure that is important for coping capability, see **Figures 5** and **6**. The IAEA guidance therefore provides advice to nuclear operators to search out any cliff edge effects that could escalate into a disaster situation as a result of extreme hazard-shocks impacting the nuclear facility [31]. In addition, the IAEA guidance advises on assessing the time frame of a nuclear power plant response once extreme events cause the more vulnerable items to fail. This vulnerability assessment process advocated by the IAEA [31] was formulated to achieve consistent and reproducible results.

Vulnerability assessment should be performed for events that are physically possible, even if they are thought to be of a very low probability and would have previously been screened out of the assessment scope. The intent here is to eliminate the possibility of screening-out a hazard from the very beginning on the basis of a frequency of occurrence which has been obtained with a large uncertainty, or (unknowingly) from incomplete or outdated information.

Similar to the European Standard EN 1991-1-7 mentioned previously [30], the IAEA's assessment methodology [31], allows for evolution of a harmonised approach to better understand what vulnerabilities exist in the man-made parts of our socio-technical fabric. Resulting conclusions about the vulnerability of regional industrial, petro-chemical and nuclear facilities that can cause a cascade of numerous emergent dangers may then be investigated for sensitivity against the generic, specific and regional civil emergency arrangements, including the overall effectiveness and efficiency of the coping strategy.

5. Objective approach to quantify coping capability

From this discussion it becomes a reasonable argument that we need to ascertain if, and how our society will be able to cope with future hazard-shock scenarios of the types identified in **Table 1**, and the increasing threat that climate change amplification introduces to escalate the scale of destructive mass consequence. Of particular importance is the need to determine if regional/local civil emergency services can cope with larger scale distributed hazard-shock triggered events, having an ever increasing severity and consequence driven by climate change.

In concept there is a limiting threshold to the capability and success of civil emergency response; this being evident with massive wildfires across South

America and Australia linked with drought conditions and climate change in 2019. It is therefore suggested that quantifying the scale of future emergent hazard-shock scenarios against the available civil emergency response capability is becoming a crucial issue that needs to be addressed with urgency.

Let us now investigate a new way of how we can model and quantify hazard-shock scenarios in terms of coping capability. The logic applied here is referenced against the overall coping capability through the complete 'Hazard-Shock Emergency Coping Cycle', see **Figure 4**.

An objective analysis can be pursued by applying the particular quantitative criteria and parameters that use relevant technical dimensions and data that is able to scale the hazard-shock preparedness, response and recovery burden—before, during and after the hazard-shock event. The deterministic parameters applied in this coping capability model have intentionally been formulated in order to ascertain the scale of demand placed on the civil emergency response organisations as they carry out their response and recovery tasks. The model formulation generically accounts for the hazard-shock's impact effect in terms of particular quantities that relate to magnitude, time, rate and space values, now using quantitative criteria and modelling parameters, as opposed to requiring expert qualitative peer judgement.

This objective analysis approach uses a phased temporal equation, progressing before, during and after any civil emergency response for a particular hazard-shock scenario [25–27], described in summary by a temporal series model using three sequential data matrices, (see **Table 2**):

- **Before** the hazard-shock event—$[P_{rB}].[H_B].[E_P].[Z_P].[D_P].[F_O]$;
- **During** the hazard-shock event—$[P_{rD}].[H_D].[V_D].[T_D].[S_D].[R_D]$;
- **After** the hazard-shock event—$[P_{rA}].[H_A].[V_A].[T_A].[S_A].[R_A]$.

Two forms of criteria are included for objective modelling, encompassing both probabilistic and deterministic mindsets, thereby allowing for integration and correlation with recognised vulnerability and risk assessment methods [28–31].

A simple summary of the model is provided in **Table 2** that outlines the 'Emergency Coping Cycle Data Matrix with Criteria and Parameters'. An important point to raise is that the model is not meant to be an exactly rigid and solvable equation or algorithm, but has been developed to reflect an interrelated series of period-demarcated matrices that conceptually simulate the hazard-shock's progressive time-history (simply thought of as being before, during and after in **Figure 1**).

The Emergency Coping Cycle Data Matrix was simply derived by considering the actual temporal sequence of an extreme hazard-shock event, while investigating the impact it has on a community and the capability of the emergency response

Mobilised action	Cycle period	Coping cycle matrix data parameters
Preparedness	Before	$[P_{rB}]. [H_B]. [E_P]. [Z_P]. [D_P]. [F_O]$
Response	During	$[P_{rD}]. [H_D]. [V_D]. [T_D]. [S_D]. [R_D]$
Recovery	After	$[P_{rA}]. [H_A]. [V_A]. [T_A]. [S_A]. [R_A]$
Qualification by experience	Quantification by data matrices	

Table 2.
Emergency coping cycle modelling criteria and parameters.

and recovery organisations to successfully cope. Using this approach, we are able to follow the temporal time-history of a particular hazard-shock's impact against the socio-technical system. We gain insight on what loss and damage occurs, the dangers that the emergency services face, as well gaining insight on how well the emergency/disaster coping strategy and its planning performs—essentially being a predictive coping capability *stress-test*.

Tables 2–5 define how the Emergency Coping Cycle Data Matrix is quantitatively represented by a temporal series data matrix. It is not an exact numerical algorithm, nor was meant to be, yet provides a reasonably intuitive model idealisation that simulates the hazard-shock temporal cycle, while employing both deterministic and probabilistic mindsets. This modelling approach now enables us to utilise powerful computing platforms that are able crunch data with relative ease, making analysis of structured masses of data a reality. The Emergency Coping Cycle Data Matrix is essentially a pre-formed structure of data blocks that enable us to question and even test accident and disaster coping strategies and their more detailed planning, underpinned by data-modelling of the type proposed here. Of particular significance will be the ability to perform iterative sensitivity studies when the criteria and parameters are varied. This also gives us the ability to optimise the coping strategy for its effectiveness and efficiency, and indicating credible risk reduction measures throughout the coping cycle.

A natural hazard event can exert an enormous force causing destruction of the built infrastructure and the resident living beings. Be it the rumble of the lower earth we stand on, a torrent of unstoppable water, the caustic suffocation and incineration by volcanic pyroclastic flow, or the seemingly explosive effect caused

Parameter	Description
P_{rB}	This parameter has two states, being (i) from past records, and (ii) future prediction with factors like climate change amplification. State (i) is the historical frequency of the collective range of severe to extreme hazard-shocks that the socio-technical system has experienced over recorded time and with 'smoking-gun' evidence. State (ii) is the predicted future collective frequency taking account of climate change amplification effects. Effectively this P_{rB} value is indicating how many times the socio-technical system/region will be exposed to hazard-shocks when the emergency responders are mobilised per year, decade and century. {It is important to also realise that the value of PrB also correlates to how frequent the civil emergency strategies and plans shall likely be executed, then informing how much demand and manning burden needs to be catered for}.
H_B	Characterisation of the hazard-shocks in terms of technical specifiers including hazard-shock the magnitude energy, impact time, rate of onset and spatial distribution of the severe to extreme hazard-shocks scenarios. {Please also refer to **Table 1** that indicates the various 'Generic Categories of Societal Hazard-Shock Scenarios', thereby indicating the demand placed on civil emergency responders}.
E_P	Exposure potential of the socio-technical system in terms of location, geography, geomorphology, human demography, population density, medical wellbeing, economic worth, resilience and sustainability, etc. {effectively describes the regional community's exposure potential in terms of loss consequences}.
Z_P	Socio-technical fabric of the region in terms of buildings, facilities, infrastructure, services, supplies, networks, plants and processes; accounting for the age and condition of the fabric.
D_P	Potential for emergent dangers to life and environment that may be triggered by hazard-shock events, covering petro-chemical processes and storage, nuclear power plants, etc.
F_O	Account of whether forewarning that the hazard-shock event is to come and how much time is likely to be available for preparation, shelter, evacuations, etc.

Table 3.
Emergency preparedness coping cycle parameters before Hazard-shock starts.

Parameter	Description
P_{rD}	Probability of success that the emergency response organisation shall be able to perform their duties for a specific character of a hazard-shock, while maintaining a flexible and adaptive capacity.
H_D	Hazards that shall be experienced by the emergency response organisation and its personnel during the hazard-shock event (not the hazard-shock itself); therefore needing to consider HAZOP review and assessment to protect personnel and enhance success for coping.
V_D	Recognised vulnerability of the region's socio-technical system against the specific hazard-shock being assessed, accounting for the (i) socio-technical fabric (Z_P), and (ii) potential emergent dangers (D_P) that can make the emergency response difficult.
T_D	Period of time for which the emergency response organisation shall be mobilised and required to continue doing their response duties for the specific character of the hazard-shock.
S_D	Spatial area that the emergency response organisation shall be required to operate in order to do their response duties for the specific character of the hazard-shock being analysed.
R_D	Primary and secondary resources that the emergency response organisation shall likely need in order to be flexible and adaptive, while also being dependent on the vulnerability of the region's socio-technical system, accounting for the (i) socio-technical fabric (Z_P), and (ii) potential emergent dangers (D_P) that can make the emergency response difficult.

Table 4.
Emergency response coping cycle parameters during hazard-shock impact.

Parameter	Description
P_{rA}	Probability of success that the emergency recovery organisation shall be able to perform their duties after the hazard-shock has passed and in the aftermath period, while maintaining a flexible and adaptive capacity.
H_A	Hazards that shall be experienced by the emergency recovery organisation and its personnel after the hazard-shock has passed and in the aftermath period; therefore needing to consider HAZOP review and assessment to protect personnel and enhance success for coping.
V_A	Recognised vulnerability of the region's socio-technical system against the specific hazard-shock being assessed, accounting for the (i) socio-technical fabric (Z_P), and (ii) potential emergent dangers (D_P) that can make the emergency recovery difficult.
T_A	Period of time for which the emergency recovery organisation shall be mobilised and required to continue doing their recovery duties for the specific character of the hazard-shock and its resultant aftermath across the socio-technical system/region.
S_A	Spatial area that the emergency recovery organisation shall be required to operate in order to do their recovery duties for the specific character of the hazard-shock being analysed.
R_A	Primary and secondary resources that the emergency recovery organisation shall likely need in order to be flexible and adaptive, dependent on the conditional aftermath that is likely to exist, while also accounting remaining dangers that can make the emergency recovery difficult.

Table 5.
Emergency recovery coping cycle parameters after hazard-shock has passed.

by extreme velocity winds from a wide hurricane/typhoon and localised tornado. The energy from these kinds of natural hazard events is released suddenly and can be without forewarning, as in the case of slippage along a fault in the earth's crust, or slowly as in the case of land subsidence.

A significant consideration is that a concentrated amount of energy is impacted over a short-time duration, and can be distributed over a massive surface area of land that includes urban and rural regions. The difference in natural hazard energy impact rate and its relative magnitude characterises the degree of destruction and overall loss that can occur. The degree of danger is dictated by the amount of energy released at a particular rate and over the hazard's duration period of exposure against the socio-technical system.

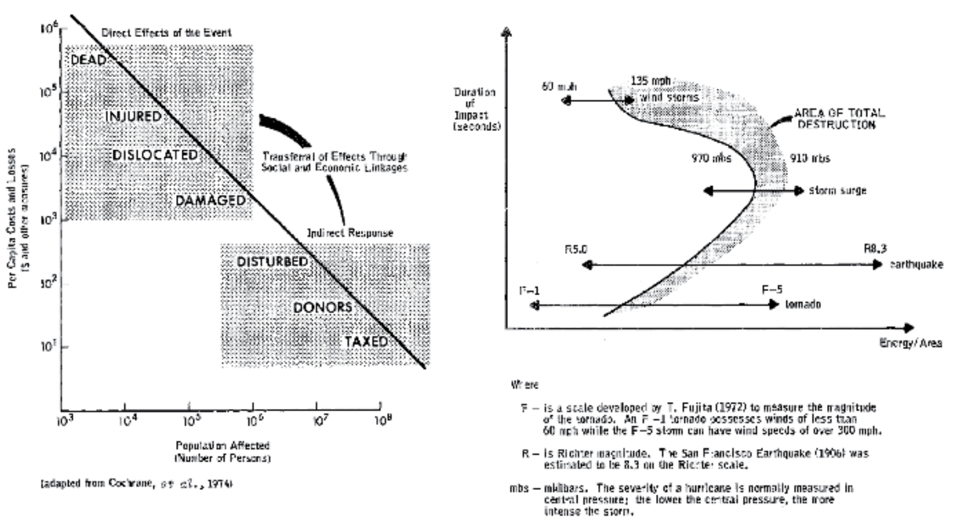
The relative robustness of the infrastructure's fabric as it is exposed to the impacting energy of the natural hazard determines whether buildings will survive or collapse, whether man's power networks keep people's homes supplied, if the road, rail and air routes can be used to supply products, and whether food supplies can get to supermarkets.

Now referring to **Tables 2–5**, the parameters 'H_D' and 'T_D', during the hazard's impact period was specifically developed in order to consider and account for the amount of hazard energy and its rate of impact. The collection of parameters grouped within the three phases of the hazard event scenario, (that is before, during and after), allow for finding characteristic relationships and trends that might otherwise be missed. For example, the ratio of $\{H_D/T_D\}$ gives us a resultant quantitative value to indicate that hazard's magnitude compared to the elapsed time period to cause damage, which may then be graphically plotted to ascertain the likely destructive potential and loss of life for a particular region and area of interest.

Looking at **Figure 7** {that is respectfully reproduced from Cochrane's work [11]}, and **Figures 8–10**, we see that Cochrane's 1975 modelling of 'Natural Hazards and their Distributive Effects', [11], may now be correlated with the present chapter's model for Emergency Coping Cycle Modelling Criteria and Parameters, **Tables 2–5**, first introduced by the author in 2016 [25–27].

The parameter Z_P that is integral of the preparedness criteria, before the hazard-shock event occurs, see **Tables 2** and **3**, is meant to represent the day to day demographic, economic and structural state of the region's socio-technical system; including recognition of the region's specific organisational readiness provided by the local civil contingency groups, whether professional or voluntary, which is of prime importance to the region's urban and rural resilience.

The generic breakdown of the components contained in the parameter Z_P, as identified in **Tables 2** and **3**, may be defined as follows:



Reproduced from "Natural Hazards and their Distributive Effects", by Harold C. Cochrane, Institute of Behavioral Science, The University of Colorado, 1975; [1].

Figure 7.
Early 1975 consequence study on the impact of natural hazards.

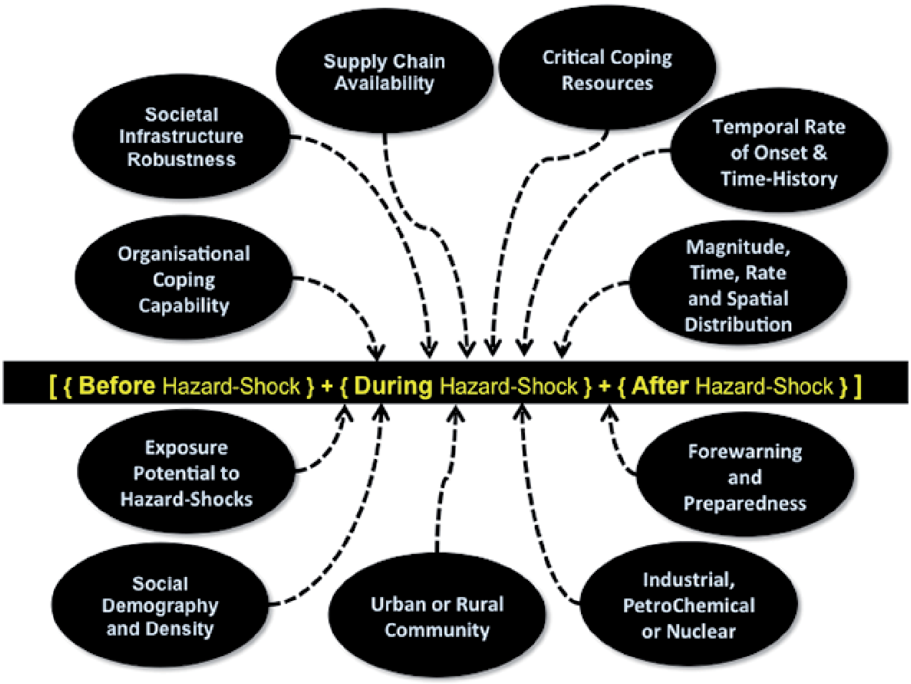


Figure 8.
Key information input data for analysis of emergency coping cycle.

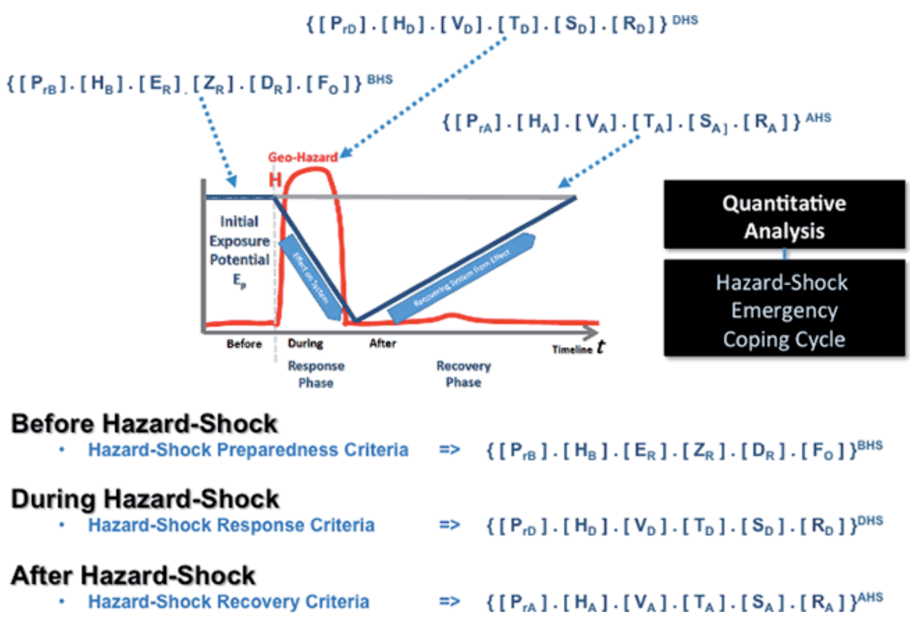


Figure 9.
Developmental basis of the emergency coping cycle data matrix.

- Organisational preparedness strategy and planning to achieve coping capability;

- Robustness of the buildings, communications, transport, networks and services;

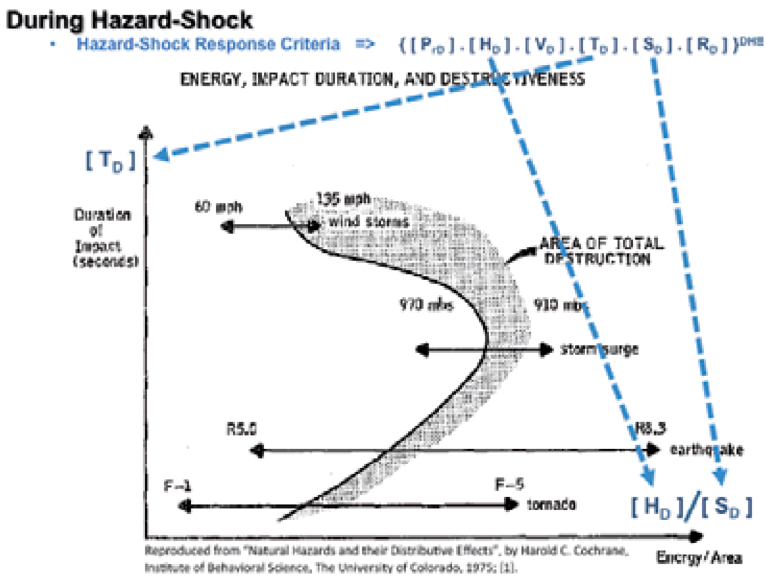


Figure 10.
Emergency coping cycle data matrix correlated with 1975 study [1].

- Availability of supply chains, especially those significant to resilience;
- Immediately ready and locally accessible critical coping resources;
- Urban and rural population densities and their spatial distribution;
- Integrity of governmental agreements, leading actors, policy makers and police.

In this instance the coping success probabilities indicated in **Table 2**, specifically P_{rD} (during the hazard-shock impact phase) and P_{rA} (after the hazard-shock impact and during the aftermath recovery phase), will result in a combined low probability of *coping success* by the civil emergency services. Hence, a probabilistic mindset for successfully coping is applied; the probabilities of P_{rD} and P_{rA} quantitatively indicate the likelihood of successfully performing the civil emergency coping activities at two periods in time:

- During the hazard-shock scenario; and,
- After the hazard-shock, with the consequential aftermath.

The similarity to hazard risk assessment [28] in terms of using the probabilistic mindset now becomes apparent, although the new Emergency Coping Cycle Data Matrix introduced in this chapter is focused on achieving *coping success*. The differentiator here being that we are trying to model the likelihood for successfully being able to cope with the impacting hazard-shock scenario. This approach enables a more rigorous appraisal of the effectiveness for coping with civil emergencies, while also being able to set objective success targets for the civil contingency management [7, 8, 13, 15, 25–27, 29] to defend society against severe and extreme hazard-shock scenarios scoped in **Table 1**.

The region's socio-technical system vulnerability allied with its organisational emergency strategy and planning is thereby being holistically tested in relation to the necessary temporal hazard-shock coping capability. And using the theoretical benchmark phases from before, to during, then after the hazard-shock impact time history, we may then (i) qualitatively assess and (ii) quantitatively analyse the success of being able to cope.

The means to provide better preparedness against hazard-shocks is initially reflected with the factor Z_P, see **Table 3**. Hence, the more likely will the success of coping be when the necessary resources during (R_D) and after (R_A) the impact event are conservatively adequate and fit for purpose, see **Tables 4** and **5**. If a preliminary coping success assessment or analysis of a region indicates that the holistic resilience of the socio-technical locality is poor, and that the required resources through the hazard-shock time history will not be available or effective, the coping capability shortfalls can be found and considered for improvement. This method should enhance coping capability and attain better risk reduction.

For 'Regular' shock scenarios advocated in **Table 1**, then the coping success probabilities of P_{rD} and P_{rA} should both be close or equal to 1. But when the shock is equivalent to an 'Overwhelming' scenario, then P_{rD} and P_{rA} will each be less—potentially below 50% chance of coping success; giving an overall product of P_{rD} times $P_{rA} = 0.5 \times 0.5 = 0.25$, or only 25% chance of coping success.

Worst of all, for a theoretical shock event that could equate to a 'Disastrous' scenario, both P_{rD} and P_{rA} will be very low indeed, no better than something like 10% for each factor; thereby resulting in an overall success for coping of the order P_{rD} times $P_{rA} = 0.1 \times 0.1 = 0.01$, or just 1% chance of coping success. [*Author's note—please keep in mind that these rough 'guestimates' are simply offered for clarification of the logic, as opposed to precise calculation that would need to be carried out in practice*].

Now let us consider the whole collection of factors that are introduced in **Table 1** from a deterministic perspective, encompassing the periods before, during and after the shock event. Starting with the factor Z_P, to the coping resources during the shock impact factored into R_D, and subsequently the resources needed to recover from the shock's aftermath with the factor R_A, are all key to gauging the complete scale of coping capability that is required for the preparedness, response and recovery activities.

We now realise that the actual real-world temporal relationship between the coping capability factors like Z_P, R_D and R_A are quite crucial in order to better understand how we might gain confidence that the organisational coping strategies and pre-plans are complete, suitable and sufficient. Essentially we can use this developmental model to test whether the emergency coping strategies and pre-plans are sound and reasonably efficient. And this form of coping capability test is flexible enough to allow for both deterministic and probabilistic viewpoints, as presented in **Tables 2–5**. Also, see **Figures 9** and **10** where we link with Cochrane's study of 1975 [11].

It is therefore advocated that the present coping capability modelling approach discussed here is amenable to further fruitful development by analysts, but here we shall concentrate purely on the logic and method of the Emergency Coping Cycle Data Matrix model. If this approach were found to be useful and of benefit to future socio-technical design and planning, in particular related to adaptation in the face of climate change effects, then the logic could be framed into a fairly simple best practice standard, similar in concept to the assessment process advocated by the subjective review of civil emergency protection earlier in Section 3. Such a standard 'template' could prove helpful in testing for consistency and continuity between different analysts, designers, planners and civil emergency services.

6. So what about climate change?

Even though James Hansen passionately appealed to the United States Senate in 1988 that global warming with resultant climate change was a distinct reality, evidenced by a sharp rise in global temperatures as a result of human activity, very little practical action has taken place to slow or correct this worrying trend in the last three decades. Global warming is now showing its *Disastrous* character (see **Table 1**) amplifying floods and wildfires as evidenced all across the world in 2019.

More recently, some scientists are becoming fearful that the usual expected hazards including earthquakes, tsunamis and volcanoes will also become more frequent with increased danger because of climate change effects. If such judgements turn out to be right, then it is expected that future natural hazards will become extremely destructive, including destruction of our built structures coinciding with mass fatality, to an extent our modern human society has not experienced in recorded times.

Our modern society uses ever greater power linked with population and industrial growth. Scientist's unofficially call this time the *Anthropocene Epoch*. We are set to have more massive and more powerful storms, greatly increased flooding, triggering major landslides, suffering with long droughts and spontaneous initiation of huge wildfires. Climate change is questioning our very survival, while civil emergency response organisations will likely have to cope with more demanding accidents and disasters.

Integral of a review and assessment process for civil contingency planning [7, 8] in the modern day is the need to properly account for an escalating stress due to climate change amplification. The stress from climate change is increasing the magnitude and frequency of natural hazard-shocks that the emergency responders will need to tackle, thereby implying that more regular periodic reviews shall be necessary to ensure that the national and regional civil contingency strategies are practicable and consistent with the range of generic societal hazard-shock scenarios.

This implies that weather born hazard-shocks which cause major impact damage with high consequence losses will be more frequent. In addition, emergency response organisations will be prone to a ratcheted rise in demand for their services, while also placing an ever-greater management and manning burden on the necessary scale and capacity to successfully respond. Therefore, if not appropriately scaled and timely to the task ahead of them, the emergency responder organisations will become less and less successful to perform their duty role.

Our society is now dense, complex and implicitly dependent on the structural fabric built up over the last few hundred years; especially in the more developed countries. And in many ways, a capitalist society also needs this type of tight interwoven society to be economically successful. The existing structural fabric was previously planned and evolved for basic function and efficiency, but without insight or account of the subsequent burden of industrialism to introduce global warming with deleterious climate change effects and dangers. In addition, if we consider the interconnected commodities trade and service networks that are used every day across the world to drive economic growth, it becomes apparent that our economy and society is potentially more vulnerable to shock-hazard scenarios that can cause massive-distributed consequences. Perrow recognised this problem of coupling and interaction of complex man-made systems allowing *normal accidents* to occur in 1984 [2].

It is therefore reasonable to judge that accidents will likely become more frequent and of greater consequential significance to disrupt the economy and to undermine the socio-technical system as a whole, in a world undergoing climate change. Our economy and wider society has an increased vulnerable to shock-hazard scenarios than ever before, resulting from denser populous, highly complex, interdependent fabric, then amplified by climate change effects.

Taking a very simple perspective, climate change causing global sea rise with additional flooding conditions will nullify and exceed past design margins of previously built defences, like with sea walls and levees. Future storms amplified by climate change are being projected to become so extreme and cause so much damage and destruction that communities and the societal infrastructure that provides service and supplies will need to recede back inland, see **Figures 2** and **3**. Dense populous merged with complex infrastructure at coastal-facing regions shall become extremely difficult to protect, **Figure 3**, even if forewarning of bad storm weather allows public evacuation.

A hot spell in the UK during February 2019, followed by a heatwave, contributed to almost 100 major wildfires, being the most ever recorded within a year. These wildfires occurred in Yorkshire, Cornwall, Dorset, Derbyshire, Northern Ireland, the Peak District, Rotherham, Wiltshire, Wales and the Highlands in Scotland. In the Autumn and early Winter of 2019, the UK experienced severe flooding events.

Our urban and rural society is becoming more vulnerable because of the conflicting stresses of our densely inter-dependent lifestyle and increasing climate change effects. A key lesson from the experience of Typhoon Hagibis that spread its fury over Japan in October 2019 was the unexpected cascading failure of Japan's seemingly modern infrastructure, services, supplies and networks. The resultant crisis was manifested by:

- Hospitals and medical care facilities being severely compromised;
- Petroleum and diesel fuel supply shortages;
- Inability to invoke emergency back-up power;
- Unavailability of water services;
- Transportation routes inhibited or just blocked;
- Supply chain distribution paralysis;
- Normal and even emergency communications network failure;
- Civil emergency services and volunteers being overwhelmed; and,
- Emergency services and other responders being overstretched and exhausted.

The scale of vulnerability is therefore sensitive to the dense coupling and interaction that is an intrinsic characteristic of our modern socio-technical society, first identified and questioned in 1984 by Charles Perrow [2], and having profound implications into the future with system failures, accidents, disasters and mass crises. More than 110,000 people were mobilised to perform search and rescue operations during and after Typhoon Hagibis. Australia is similarly experiencing a record heatwave with mammoth wildfire blazes in the latter part of 2019, scorching millions of hectares of land, over a thousand houses burnt down, numerous human fatalities, wildlife unable to survive and firefighters becoming exhausted without respite.

Governments and regional authorities will have to supplement standard risk assessment techniques with a wider consideration of societal resilience and infrastructure robustness. And this is becoming a tangible issue for not only lesser developed countries, but also for highly evolved countries like the UK. Protection against future accidents, and possible escalating disaster amplified by climate change effects, shall need to assess the risk, but also practically consider the adequacy of the emergency response coping capability, accounting for the overall temporal time of an accident or disaster—before, during and after. A much more efficient and effective civil emergency response capability is perceived to be of major imperative.

7. Why and what next?

None of us wish for accidents or disasters that evolve into crisis situations. None of us wish to die prematurely. None of us wish for our children, nor our children's children, to suffer because of our mistakes. Day to day in our normal, and usually happy lives, thinking about awful things is not nice. We all like to be content and free from danger. And businesses want to be positive, intrinsic of a growing and prosperous economy. In a responsible society, we try to instill a duty of care for ourselves and to others. We vote for our democratic governments in order for them to make decisions on our behalf, the public expectation being that governments shall maintain our well-being, safety and security now and into the future.

We do what we believe is right for the livelihood of our families, businesses account for things that can go wrong to affect their profitability, and governments are always looking towards the horizon for things that could happen to reduce their country's GDP, the signs of medical pandemics, together with unprovoked events like military and cyber-attack. The range of things that can go wrong are accounted for in a large company's risk register, and the CEO asks of their organisation and its management whether adequate protection and mitigation measures are in place.

But sometimes people take stark denial approaches to particular societal stresses, shocks and future emergent threats or hazards. If the public had their own risk register, what items would be mentioned? Premature death would most likely be the first priority mentioned, whether caused by a road accident or cancer, hence the need for a medical health service. The next item on the public risk register is likely to be unemployment that shall threaten their personal ability to pay the house bills and feed the family. Then a proportion of the public are going to indicate their concern for being flooded out of their homes, while the occurrence of fire is likely to be mentioned too. Hence the need for emergency services to quickly respond and protect the public in developed countries.

The practical reality is that different groups of people around the world will have a wide spectrum of risk concerns. People perceive and judge their own vulnerability in diverse and sometimes perplexing ways. Into the future we face the high probability (towards certainty) that we shall have to cope with the planet's usual natural hazards, combined with and amplified by, the increasing stress of global warming [18, 13–16].

Concerns for the earth's biosphere under the stress of human activity is not new. As early as the eighteenth century, Alexander Von Humboldt identified human kind's effect on the natural world [32], then George Perkins Marsh at the time of the American Civil War in 1863 [33] stated his concern. Other people—scientific researchers, public news outlets and even the youngest of our society, have consistently questioned the dilemma that exists with population growth, human consumption and a changing climate [10, 11, 13–16, 34].

A fundamental question facing human kind is whether our society will be able to cope with more onerous future stresses, shocks, hazards and threats into the future that can either cause accidents, or make them worse by amplifying the accident's effect and its aftermath consequences? This introduces the need to better model whether our existing preparedness, response and recovery plans and capability is in fact adequate against the hazard-shock scenarios that will impact us in the near future. The preparedness, response and recovery measures should therefore be properly modelled using quantitative criteria and parameters, specifically simulating hazard scenario's magnitude, time, rate and spatial dimensions.

Whatever the risk register may contain, the risk assessment methodology used to establish the risks does not indicate whether the emergency services with their duty responders will be able to do what is required, and whether they shall ultimately cope with the unravelling crisis. In essence, this chapter puts forward a means to objectively assess society's capability to cope when faced with major hazard-shock scenarios in the context of an uncertain and potentially more dangerous future. The basic premise applied here then is to ascertain the ability to cope throughout the period of the emergency scenario.

Author details

Paul Smith
The Institute of Civil Protection and Emergency Management (ICPEM), London, UK

*Address all correspondence to: paul-c.smith@arup.com

References

[1] The Official Report of The Fukushima Nuclear Accident Independent Investigation Commission. The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission; 2012

[2] Perrow C. Normal Accidents: Living with High-Risk Technologies. 1984

[3] Mileti DS. Disasters by Design. The Changing Risk Landscape: Implications for Insurance Risk Management; 1999

[4] Taleb NN. The Black Swan: The Impact of the Highly Improbable; 2007

[5] Casti J. X-Events: The Collapse of Everything; 2012

[6] UK Control of Major Accident Hazards Regulations (COMAH); 2015

[7] UK Civil Contingencies Act (CCA); 2004

[8] UK Civil Contingencies Regulations; 2005

[9] Cochrane HC, Eugene Haas J, Bowden MJ, Kates RW. Social Science Perspectives on the coming San Francisco Earthquake—Economic Impact, Prediction and Reconstruction. Natural Hazard Research; 1974

[10] White GF, Eugene Haas J. Assessment of Research on Natural Hazards. NSF-RA-E-75-001. Cambridge, MA, USA: MIT Press; May 1975. ISBN: 9780262080835

[11] Cochrane HC. Natural Hazards and their Distributive Effects. Institute of Behavioral Science, Program on Technology, Environment and Man Monograph, NSF-RA-E-75-003. Institute of Behavioral Science, University of Colorado, Library of Congress Catalog Card No. 75-620047; 1975

[12] Chambers R. Challenging the Professions: Frontiers for Rural Development. The Schumacher Centre Bourton on Dunsmore, Rugby, Warwickshire CV23 9QZ. UK: Intermediate Technology Publications, Practical Action Publishing Ltd.; 1993. ISBN: 978-1-85339-194-1

[13] Intergovernmental Panel on Climate Change (IPCC). 5th Assessment Report of 2014. 2014

[14] Mann ME, Kump LR. Dire Predictions: Understanding Climate Change. The Illustrated Guide to the Findings of the IPCC. UK: DK, Penguin Random House; 2015

[15] Plag H-P, Brocklebank S, Brosnan D, Campus P, Cloetingh S, Jukes-Plag S, Stein S. Extreme Geohazards: Reducing the Disaster Risk and Increasing Resilience. A Community Science Position Paper. ESF, GEO and GHCP; 2015

[16] Canada Wildfires: Justin Trudeau Visits Fort McMurray, Canada. BBC News. 13th May 2016

[17] Coenraads R. Natural Disasters and How We are to Cope. Elanora Heights, NSW, Australia: Millenium House, Chief Consultant Robert Coenraads; 2006. ISBN-10: 1921209119, ISBN-13: 978-1921209116, ASIN: B00469R4AA

[18] Adaptation, adaptive capacity and vulnerability. Global Environment Change. 2006;**16**:282-292

[19] Development and Review of Plant Specific Emergency Operating Procedures. IAEA Safety Report Series No. 48. Vienna: International Atomic Energy Agency; 2006

[20] IAEA Safety Standards. Arrangements for Preparedness for a Nuclear or Radiological Emergency.

Safety Guide No. GS-G-2.1. Vienna: International Atomic Energy Agency; 2007

[21] UK's Cabinet Office. Keeping the Country Running: Natural Hazards and Infrastructure, A Guide to Improving the Resilience of Critical Infrastructure and Essential Services. Open Government Licence, UK Government Publication: HM Crown Copyright; October 2011

[22] Wisner B, Gaillard JC, Kelman L. The Routledge Handbook of Hazards and Disaster Risk Reduction. London, New York: Routledge, Taylor & Francis Group; 2012

[23] Emery FE. Systems Thinking: Selected Readings. Harmondsworth, Middlesex, England: Penguin, Education, Penguin Books Ltd.; First Published in 1969

[24] Checkland P. Systems Thinking, Systems Practice. UK: John Wiley & Sons; 1981. ISBN 10: 0471279110, ISBN 13: 9780471279112

[25] Smith P. The "severe shock event risk" (SSER) calculation for future risk analysis. In: TINCE-2016, Paris, September 5th to 9th. 2016

[26] Smith P. The importance of the severe shock event coping cycle for resilience. In: TINCE-2016, Paris, September 5th to 9th. 2016

[27] Backstrom O, Smith P. Future probabilistic risk simulation of severe shock events & accidents. In: TINCE-2016, Paris, September 5th to 9th. 2016

[28] ISO/IEC 31000. Risk Management—Risk Assessment Techniques; ISO International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401 - 1214. Vernier, Geneva, Switzerland; 2019

[29] Wisner B, Blaikie P, Cannon T, Davis I. At Risk: Natural Hazards, People's Vulnerability and Disasters. 2nd edition. Wisner, Blaikie, Cannon and Davis. Routledge, United Nations: Hyogo Framework for Action; 2005

[30] General Actions - Accidental Actions, European Standard. European Standard. Eurocode 1, Actions on Structures, Part 1-7: General Actions—Accidental Actions, EN 1991-1-7. Brussels: European Committee for Standardisation; 2007

[31] Assessment of Vulnerabilities of Operating Nuclear Power Plants to Extreme External Events. IAEA-TECDOC-1834. Vienna: IAEA Safety Standards and Related Publications, International Atomic Energy Agency; 2017

[32] Wulf A. The Invention of Nature: The Adventures of Alexander Von Humboldt, The Lost Hero of Science. UK: John Murray Publications Ltd; 2016

[33] Marsh GP. Man and Nature, or, Physical Geography as Modified by Human Action. Seattle, London: Weyerhaeuser Environmental Classics, University of Washington Press; 2003

[34] Thomas WL Jr. Man's Role in Changing the Face of Earth. Chicago, London: The University of Chicago Press; 1956. Republished in 1967

Edited by Murat Darçın

Accidents are inevitable in our lives and they affect us in many aspects ranging from economical to social, health to legal. While it is not possible to remove accidents from our lives completely, it is possible to develop new techniques or set new standards or prepare contingency plans to reduce their possibility of happening or to alleviate their consequences. This book, aiming to enlighten our ways to prevent accidents, is a compilation of articles authored by reputable international academicians from several disciplines such as maritime studies, defense technologies, emergency management, and psychiatry and behavioral medicine.

Published in London, UK

IntechOpen

ISBN 978-1-83881-963-7