REF2021

Institution: University of Strathclyde		
Unit of Assessment: B12 Engineering		
Title of case study: IMO regulations promote safety and innovation in the global maritime industry		
Period when the underpinning research was undertaken: 2000-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Dracos Vassalos	Professor	09/10/1980 – present
Osman Turan	Professor	12/12/1994 – present
Evangelos Boulougouris	Professor	03/01/2013 – present
Gerasimos Theotokatos	Professor	03/01/2013 – present
Iraklis Lazakis	Reader	05/09/2011 – present
Rafet Kurt	Senior Lecturer	01/02/2012 – present
Period when the claimed impact occurred: August 2013 – July 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Global maritime safety has been influenced by a range of collaborative research projects led by researchers in Naval Architecture Ocean and Marine Engineering at Strathclyde. Key findings were applied directly in the regulation-making process in the International Maritime Organisation (IMO) from January 2014 onwards; these regulations affect all commercial shipping operating up to December 2019, with important amendments informed by Strathclyde research introduced from January 2020. IMO regulations ensure a safety level is maintained, using a 'risk-based' approach to foster innovation in design and operation of over 12,000 commercial vessels since August 2013. IMO regulations have directly led to reduction in loss of and damage to ships, reduction in injuries and loss of lives at sea, and supported economic benefits to the global maritime and insurance sectors.

2. Underpinning research

The International Maritime Organisation (IMO) is the United Nations agency responsible for safety, security and pollution prevention in international shipping and promotes standards, which influence the whole life cycle of maritime assets. These standards are in the form of International Conventions, such as the Safety of Life at Sea (SOLAS) regulations, which govern the design and operation of the merchant fleet with around 60,000 large merchant vessels (over 500 gross tonnes) transporting around 11 billion tons of goods and millions of crew and passengers around the world each year. Since 2000, a sustained programme of research involving six key academics noted above and over 50 other researchers in Naval Architecture Ocean and Marine Engineering at the University of Strathclyde has directly influenced the content and nature of SOLAS regulations, and hence the safety culture in the maritime industry. Key contributions to maritime safety are based on a significant body of research including:

Introduction of the 'Design for Safety' approach, leading to a paradigm shift in maritime safety regulations. This body of research established safety as a quantifiable design objective, using the principle of Goal Based Standards (GBS) to identify/quantify risks and achieve safety goals, as opposed to safety achieved by rule compliance. Over the past 20 years, the pace of technological development in the maritime industry led to unprecedented changes and safety challenges that could only be met by risk-based approaches, rather than frequent prescriptive rule changes. In 2000 Strathclyde researchers instigated and established a large-scale EU Thematic Network in maritime safety to promote the 'design for safety' philosophy, to implement Risk-Based Design in industry and then to develop and take this risk-centric regulatory framework to IMO [R1].

Vassalos and his research group proposed a methodological treatment of the dynamics of damaged ships while addressing the ensuing risk of flooding and offering solutions to the industry [R4]. They developed and introduced techniques to measure safety and assess the performance of ships following incidents such as collision and grounding, leading to large scale flooding. The methodology enabled causal chains of events to be studied systematically to understand what happened, when, how and why, leading to better-informed prevention, mitigation and control strategies and measures. A substantial body of research over 20 years examined target risk contributors and barriers, which included intact stability [R3], damage stability [R4], fire [R1], efficiency in ship systems through energy flows [R2], passenger evacuation [R3], health monitoring of marine systems and structures [R5], quantification of the human factors contribution to maritime safety, safety culture and awareness [R6], risk analysis and assessment tools [R1, R4]. The development of scientific first-principles tools such as software, databases, and frameworks, allowed maritime safety to be assessed directly and quantitatively for the first time.

Life cycle risk management: In the maritime industry, new regulations apply only to ships laying keel after a given regulation has been enforced. This can leave 90% of the existing fleet operating at inferior standards, compared to new designs. Addressing this gap, several EU-funded H2020 projects led by Strathclyde (2019-2022), e.g. FLARE, SAFEPASS, AUTOSHIP, have involved key industry stakeholders to develop the requisite tools and, through IMO, an unprecedented regulatory framework for life cycle risk management, to address safety of all new and existing ships with any available cost-effective means [R4]. With the development of software and modelling tools, researchers at Strathclyde have enlarged the platform of cost-effective solutions for life cycle risk management, for example by addressing environmental risk and energy efficiency over the lifespan of the vessel, to encompass design, operation and retrofitting [R2]. Innovative measures linked to human factors, outcomes of the SAFEMODE project (2019-2022), have been applied to maritime safety. Similarly, the EU FP7 SEAHORSE project (2013-2016), led by Turan, addressed human and organisational errors in maritime accidents, for example through transfer of well-proven practices and methodologies from air transport to marine transport [R6].

3. References to the research (Strathclyde affiliated authors in **bold**)

R1 **Vassalos, D** (Chapter 2: Risk-Based Ship Design) in Papanikolaou, A (Editor). *Risk-Based Ship Design – Methods, Tools and Applications*. Springer, October 2008, ISBN 978-3-540-89042-6, pp 17-98. (Available from HEI on request)

R2 Cichowicz, J, **Theotokatos, G** and **Vassalos, D**. (2015) Dynamic energy modelling for ship life-cycle performance assessment, *Ocean Engineering*, Volume 110, Part B, pp 49-61. DOI: https://doi.org/10.1016/j.oceaneng.2015.05.041

R3 Lu, J., Gu, M. and **Boulougouris, E.**, (2019) Model experiments and direct stability assessments on pure loss of stability of the ONR tumblehome in following seas, Ocean Engineering, Vol. 194, 14p. DOI: https://doi.org/10.1016/j.oceaneng.2019.106640 [REF2]

R4 **Vassalos, D.**, (2020) The Role of Damaged Ship Dynamics in addressing the Risk of Flooding, *Journal of Ships and Offshore Structures.* https://doi.org/10.1080/17445302.2020.1827639

R5 **Cheliotis M**, **Gkerekos C**, **Lazakis I**, **Theotokatos G.** (2019) A novel data condition and performance hybrid imputation method for energy efficient operations of marine systems. Ocean Engineering, 188, 106220. 1-14. https://doi.org/10.1016/j.oceaneng.2019.106220

R6 **Turan, O**, **Kurt, R**, **Arslan, V**, Silvagni, S, Ducci, M, Liston, P, Schraagen, JM, Fang, I, Papadakis, G. (2016) Can We Learn from Aviation: Safety Enhancements in Transport by Achieving Human Orientated Resilient Shipping Environment. *Transport Research Arena TRA2016*, Transportation Research Procedia, 14, pp 1669–1678. https://doi.org/10.1016/j.trpro.2016.05.132

Notes on the quality of research: Underpinning research has been published either following rigorous peer review, or by recognised academic publishers. The research has been consistently supported by significant funding from EU FP7, H2020, international maritime industry and UK Government sources, amounting to 30 projects and over GBP13,000,000 in grants over a period of 11 years. In 2017, the SEAHORSE project (e.g. R6) won the RINE-LR Marine Safety Award. For his contribution to maritime safety Professor Vassalos received a Life Achievement Award from the Royal Academy of Engineering in 2011, the Gold Medal from the Royal Institution of Naval Architects in 2012, and the Gold Medal from the Society of Naval Architects and Marine Engineers in the USA in 2015. In 2019, he was elected Fellow of the Royal Academy of Engineering.

4. Details of the impact

Through sustained collaboration with the IMO and the maritime industry, both during the research process and in disseminating the research outcomes, Strathclyde researchers have contributed to significant improvements to maritime safety and innovative legislation and practice. In particular, the researchers' participation in IMO Working Groups (for the original SOLAS 2009 regulations and bi-annual amendments from January 2014 onwards) and their promotion of collaborative working in the maritime industry through Centres of Excellence (including the Maritime Safety Research Centre, Maritime Human Factors Centre, and Safety and Risk Doctoral Training Centre) have been key drivers in these changes. The researchers also established University spin-out companies, Safety at Sea Ltd (1999-2014) and Maritime Safety Innovations Ltd (2017-present), with maritime industry leaders to provide consultancy and training, and promote innovative safety solutions with emphasis on life cycle risk management. They have organised and participated in international industry-academia conferences and workshops to transfer knowledge from the research. In this way, the following demonstrable impacts have been achieved:

Informing legislation adopted by and promoted through the IMO

The IMO's rules are the most important international instrument addressing maritime safety in the global merchant fleet, covering areas such as ship design, construction and equipment, subdivision and stability, fire protection, radio-communications, safety of navigation, carriage of cargoes (including dangerous cargoes), safety management and maritime security. The merchant fleet also includes all passenger ships (carrying more than 12 passengers) on international voyages, with millions of passengers travelling on such ships each year.

Vassalos and Boulougouris have provided expertise and input from research projects to various regulatory working groups through the UK Government delegation to IMO, (including Formal Safety Assessment Group, Environmental Impact Group and Safety of Domestic Ferries Group) [**S1**]. They have influenced bi-annual amendments to the SOLAS 2009 regulations, which were in force until December 2019, and a series of important amendments introduced from January 2020. The Director of IMO's Maritime Safety Division confirms that: '*Strathclyde-led projects … provided the inspiration and supported the development of several maritime safety-defining initiatives that paved the way to complete modernisation of maritime safety. Noteworthy are also a number of technical presentations at IMO by Strathclyde to nurture wider understanding and support a fast-pacing regulation process over the recent past*' [**S1**].

Principal to these contributions is the introduction of the 'design for safety' approach, based on the Strathclyde research, which led to the adoption of goal-based standards (GBS) within all SOLAS regulations. The importance of this approach is confirmed on the IMO website: '*IMO Member Governments have started approaching safety from a completely new perspective – one that is goal and performance oriented, in lieu of the traditional prescriptive-based approach, taking into account the sophisticated nature of the maritime industry*' [**S2a**]. The GBS approach continues to influence the regulation process of the IMO. The latest IMO instruments using the GBS approach to monitoring safety are the Polar Code (which came into force from January 2017), the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code; adopted June 2015), and ship construction standards for bulk carriers and oil tankers of 150m in length and above (adopted in 2012, came into force for vessels with a building contract placed on or after 1st July 2016) [**S2a**].

Amendments to SOLAS regulations on subdivision and damage stability were adopted from June 2015, to update rules for international cargo and passenger ships [**S2b**]. Damage stability failure represents 90% of the risk to human lives in maritime accidents, and as a ship is subdivided into compartments, it must be able to withstand flooding in one or more compartments without sinking. Revisions were based on findings from Strathclyde led EU funded collaborations, such as GOALDS (Goal Based Damage Stability) and FLOODSTAND (Integrated Flooding Control and Standard for Stability and Crises Management) [**S1**].

Further amendments on damage stability regulations came into effect in January 2020, relating to subdivision of passenger ships [**S2b**]. IMO's involvement in regulation of domestic ferry safety began with the Manila Conference in the Philippines in 2015, based on the work undertaken by Strathclyde and World Maritime University, Sweden, with Vassalos acting as lead consultant on behalf of IMO [**S1**, **S2c**]. This led to the adoption of the 'Manila Statement', which acknowledged the urgent need to enhance the safety of domestic ferries and urged States to review and update national regulations in relation to their passenger ferries [**S2c**]. While domestic ferry operations are not required to comply with SOLAS, the IMO notes that now '*many countries base their* *regulations on the IMO standards*' and the IMO has issued a set of standards comprising regulations and model national legislation applicable to non-SOLAS ships [**S2c**].

Embedding a safety culture in maritime industry

The adoption of the 'design for safety' approach and subsequent changes to the regulatory process has overcome previous resistance to safety improvements in the industry, as the regulations are no longer saturated with risk-control. Maritime safety was once treated as a costly, damage limiting exercise, with design changes and safety regulation made in response to disasters at sea such as the sinking of the Estonia in 1994 when 852 people died. The risk-based approach to ship design enabled regulators such as IMO to set the right level of safety, designers to plan for requisite safety margins and ship owners to manage impending risks, all parties achieving this cost-effectively. The Director (2001–2016) of the Directorate for Mobility and Transport (European Commission) confirms that '*Strathclyde have more often than not acted in a co-ordinator role in many maritime safety initiatives*' and this research has '*defined the evolution and direction of maritime safety*' [**S3**]. Similarly, the Senior Vice President DNV GL, a Classification Society which offers knowledge-based services to ship owners, shipyards, system suppliers and other stakeholders in the maritime industry, comments that *'one of the key developments in these [Strathclyde] projects was methods, tools and data leading to estimation of the safety level of ships, a distinct revolutionary change in maritime safety … that has helped transform both the evolution of safety as well as the focus, opening the door to innovation and facilitating technological breakthroughs'* [**S4**].

Supporting innovation in ship design and operation

All new merchant ships built worldwide must comply with SOLAS 2009 regulations and all subsequent amendments. The European Maritime Safety Agency (EMSA) reports that in 2018 there were 12,048 'new' merchant ships in the global fleet between 0 and 4 years of age, ranging from cargo and container ships, bulk carriers, oil, chemical and gas tankers, passenger ships and fishing vessels [**S5**] all designed and then constructed under SOLAS regulations.

Safety assessment at the design stage affects the maritime industry in many ways apart from safety of operation. It provides safety assurance for novel concepts, fostering and supporting innovative designs such as megaships and battery-driven ships. It has facilitated the introduction and growth of innovations such as digital and autonomous ships, and enabled integration of novel concepts in ship design, such as safety centres and developments in life-saving equipment.

The Head of Engineering at Meyerwerft, one of the most innovative shipyards in the world, comments that he promotes *'the full positive impact of these advances in ship design, particularly the design for safety, among the industry*' and confirms the now industry-wide application of Strathclyde research to assess safety at the design stage, in particular *'advanced simulation tools addressing damage stability and risk of flooding in daily design of passenger ships'* [**S6**].

The new Royal Caribbean Cruise Line (RCCL) Icon megaships currently under construction can accommodate 10,500 people on board. They are described as the ultimate lifeboat, demonstrating through direct assessment that the ship can survive any realisable flooding accident scenario. The Executive Vice President of RCCL highlighted that the *'new holistic approaches to safety, inspired by Strathclyde, are enabling us to raise the safety bar in all our ships with ingenious ways never thought possible before .... mega ships are a product of partnerships .. with Strathclyde as strategic partner'* [**S7**]. The RCCL website notes that *'All of our ships are designed and operated in compliance with the strict requirements of the International Maritime Organization, the UN agency that sets global standards for the safety and operation of cruise ships, codified in the Safety of Life at Sea (SOLAS) Convention. Safety-related regulations are rigorous – and we often go above and beyond what is required; for example, carrying backup mechanical, navigational and safety provisions'* [**S8**].

Reduction in loss of vessels, life and injuries at sea

The Allianz Review of Global Shipping (2019) reports annual total loss of vessels over 100GT has fallen substantially from 207 reported in 2000 to only 46 vessels in 2018 [**S9**]. The review confirms that annual losses are now at their lowest level this century, and since 2009, when SOLAS regulations first came into force, shipping losses have declined by 65%. The Allianz report highlights that '*improved ship design and technology, stepped-up regulation and advances in risk* *management and safety are driving the sector's long term loss improvement. More robust safety management systems and procedures on vessels is also a factor in preventing breakdowns, accidents and other mistakes from escalating into total losses'*. [**S9**]

Passenger safety in the European shipping sector has also improved. The European Maritime Safety Agency (EMSA) recorded a 57% drop in the number of fatalities between 2014 and 2019 from 114 to 49, and a 26% reduction in injuries to passengers and crew from 1239 to 917 over the same period (data based on statistics gathered from the accident investigation bodies of the EU) [**S5**]. The Director of the Directorate General for Mobility and Transport (European Commission) confirms that with support from Strathclyde research the *'development of regulations for passenger ships has helped the European Community to take a leading position in the process and .. help crystallise probabilistic regulations with emphasis on passenger ships, leading over the years to sustained improvement in maritime safety and a continuing downturn in loss of life at sea'* [**S3**].

Economic benefits to global maritime and UK insurance sectors

The continued safe operation of commercial shipping is essential for the economic success of the global maritime sector. By 2019, the total value of the annual world shipping trade had reached more than 14 trillion US Dollars (International Chamber of Shipping data). The Director of Safety at DNV GL states that '*through collaboration with Strathclyde we have developed a series of unique scientific methods and tools… to enhance our service offerings to the satisfaction of our customers, adding value to the whole maritime value chain*' [**S4**]. Reductions in losses reduce claims on and economic loss to the insurance sector. This is particularly significant for the UK, which has a 35% share of global marine insurance premiums, 60% of protection and indemnity insurance and 26% of total global shipbroking. Analysis by Allianz Global of 230,000 marine insurance industry claims, with a value of almost USD10,000,000,000 (07-2018), between July 2013 and July 2018 [**S9**] shows that ship sinking/collision incidents are the most expensive cause of loss for insurers, accounting for 15% of the value of all claims – equivalent to more than USD1,500,000,000 (07-2018) over this period.

Improvements in maritime safety - stemming from regulations informed by Strathclyde-led research and tools developed by Strathclyde to support ship design and operation practices – have resulted in fewer vessels lost and fewer fatalities, representing a significant benefit to the global economy and to the safety of passengers and crew.

5. Sources to corroborate the impact

S1 Corroborating statement from the Director of the Maritime Safety Division at IMO, dated 5 May 2020.

S2 Web content from International Maritime Organization:

a. IMO Goal-based standards. https://bit.ly/3refRwq
b. Safety and environmental standards on passenger ships. https://bit.ly/3sLDgWa
c. Philippines domestic ferry safety conference urges action to improve safety record. https://bit.ly/386dTqc

S3 Corroborating statement from the Director (2001–2016) of the Directorate for Mobility and Transport (European Commission), dated 30 November 2020.

S4 Corroborating statement from the Director of Safety, DNV GL, dated 12 August 2020.

S5 Collated reports from The European Maritime Safety Agency (EMSA).

S6 Corroborating statement from the Head of Engineering, Meyerwerft.

S7 Corroborating statement from the Executive Vice President, Royal Caribbean, dated 30 November 2020.

S8 Royal Caribbean, "Safety and Security". https://bit.ly/3g9MPJy

S9 Allianz Global Shipping Review 2019.