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| **Institution:** Liverpool John Moores University (LJMU) | | |
| **Unit of Assessment:** Sub-panel 12: Engineering | | |
| **Title of case study:** RAIDS - A Risk Assessment Informed Decision Support Tool for Large Maritime Engineering Systems | | |
| **Period when the underpinning research was undertaken:** 2000 to 2019 | | |
| **Details of staff conducting the underpinning research from the submitting unit:** | | |
| **Name(s):** Ian Jenkinson (IJ), Sean Loughney (SL), Alan Wall (AW), Jin Wang (JW), Zaili Yang (ZY) | **Role(s):** IJ (Professor), SL (Lecturer), AW (Reader), JW (Professor), ZY (Professor) | **Period(s) employed by submitting HEI**: IJ (Prof. 2006-2020), SL (RS 2014-17; PDRA 2017-19; L 2019-20), AW (L 2000-04; R 2004-19), JW (R 1999-02; Prof 2002-date), ZY (RS 2003-06; PDRA 2006-07; L 2007-10, R 2010-14, Prof. 2014-date) |
| **Period when the claimed impact occurred:** August 2013 to December 2020 | | |
| **Is this case study continued from a case study submitted in 2014?** N | | |

## 1. Summary of the impact

The research has had a direct quantifiable impact on both regulatory and public policy governing risk-based maritime systems operations, and the practices and activities of industrial organisations and services. A systematic decision-support methodology, together with a series of associated sector-specific models, has influenced industrial practice by shaping a goal-setting regime for maritime systems operations. The range of organisations influenced by the research has included regulatory and classification bodies (UK Health and Safety Executive (HSE) and Lloyd's Register (LR)), maritime operators (Shell, Ministry of Defence (MoD), Three Gorges Navigation Authority, Siemens and Shanghai Pilot Station) and consulting companies (Risktec), in the UK and internationally.

## 2. Underpinning research

Over the past two decades, the maritime industry has been moving towards a pro-active, risk-based, goal-setting regime, from a largely prescriptive one. This has necessitated the development of RAIDS - A Risk Assessment Informed Decision Support Tool to address issues relating to the incompleteness, fuzziness and ambiguity of data associated with the unique design and operational characteristics of large-scale maritime engineering systems such as ocean-going ships, port terminals and offshore installations. In response, a series of innovative concepts, methods and models using data under uncertainty has been developed at the Liverpool Logistics, Offshore and Marine (LOOM) Research Institute since 2000, which has resulted in significant modelling advances in maritime technology. The focus has been on the extension of risk-based decision-making and the development of holistic and generic models and methods for knowledge-driven risk assessment and decision analysis. A number of external grant-funding sources including the EPSRC, EU and the HSE has supported the research in this area [RPs 1-12].

The development of the analysis models in this case study involved the investigation of a range of techniques, including Evidential Reasoning [ROs 1, 4], a risk matrix approach [ROs 2, 5], Bayesian Networks [RO 3], and multi-criteria decision-making [RO 6]. Many of these models have been developed and published in collaboration with industrial partners, with the detail reported in conference/journal publications, industrial guidelines/reports and completed PhD theses. All of the research projects included in this case study have involved collaboration with industrial partners, with industrial impact verified by LJMU researchers who have remained on site to test and validate the research outcomes.

Industrial impact at the operational, managerial and strategic levels have been associated with:

1. The revision of maritime safety regulations associated with maritime systems design and operation, maritime accident investigations and human and organisational factors [ROs 4, 5].
2. Safety/security planning for large marine engineering systems, ship selection and safety management [ROs 2, 3].
3. The operation of ships, port terminals and offshore installations, specifically related to maintenance planning, evacuation planning, operational strategy planning and the selection of risk control measures [ROs 1, RO 6].

RAIDS as a tool with a number of supporting models enables safety to be considered as a quantitative design/operational objective, contributing to a fundamental shift in the maritime and

offshore industries. The research, funded by HSE, EU and EPSRC in collaboration with Shell, LR and ABS, has enabled determination of risk of offshore installation/ship collisions and implementation of risk control measures in offshore installation design and operation [RPs 1, 2, 6, 9, 10, 12], providing guidelines for offshore stakeholders both in the UK and internationally. This research has led to risk estimation and decision models that can be used under high uncertainties in data. The research, funded by EPSRC and EU in collaboration with Peel, MoD and MCA, has developed risk-informed verification, certification and design selection models [RPs 3, 4, 5], facilitating the implementation of risk-based verification and updating the codes of practice for ships and offshore installations in order to ensure that safer designs and operational strategies can be generated cost-effectively. The research funded by EU and government bodies in collaboration with industrial partners has led to the improvement of their businesses and efficiency [RPs 7, 8, 11].

## 3. References to the research

Cited research outputs (all papers have been through a rigorous peer-review process):

**RO 1:** Asuquo M.P., Wang J., Zhang L., Phylip-Jones G. (2019), "Condition monitoring of marine and offshore machinery using evidential reasoning techniques", *Journal of Marine Engineering & Technology*, 2019 (doi.org/10.1080/20464177.2019.1573457).

**RO 2:** Fang Q.G., Yang Z.L., Hu S.P., Wang J. (2005), "Formal safety assessment and application of the navigation simulators for preventing human error in ship operations", *Journal of Marine Science and Application*, Vol.4, No.3, 5-12 (doi.org/10.1007/s11804-005-0014-3).

**RO 3:** Loughney S., Wang J., (2017), "Bayesian network modelling of an offshore electrical generation system for applications within an asset integrity case for normally unattended offshore installations", *Institution of Mechanical Engineers Part M - Journal of Engineering for the Maritime Environment,* (doi.org/10.1177/1475090217704787).

**RO 4:** Ma, F., Chen, Y. W., Huang, Z. C., Yan, X. P., Wang, J., (2016) "A novel approach of collision assessment for coastal radar surveillance", *Reliability Engineering & System Safety*, Vol.155, 179-195 (doi.org/10.1016/j.ress.2016.07.013).

**RO 5:** Wang J., Matellini D.B., Wall A., Phipps J. (2012), "Risk-based verification of large offshore systems", *Proceedings of the Institution of Mechanical Engineering Part M – Journal of Engineering for the Maritime Environment*, Vol.226(M3), 273-298 (doi.org/10.1177/1475090211430302).

**RO 6:** Yang Z., Wang J., Bonsall S., "Approximate TOPSIS for vessel selection under uncertain environment", *Expert Systems with Applications*, Vol.38, Issue 12, 2011, 14523-14534 (doi.org/10.1016/j.eswa.2011.05.032).

Research projects/grants of particular relevance to this case study are as follows:

**RP 1:** Wang J., Yang J., Jenkinson I., "Application of approximate reasoning methodologies to the offshore design process", *EPSRC* (GR/R32413/01 & GR/R30624/01), £173,844; 2001-2004.

**RP 2:** Wang J., Jenkinson I.D., "A novel and advanced decision support tool for offshore operations", *EPSRC* (GR/S85504/01 & GR/S85498/01), £226,602; 2004-2007.

**RP 3:** Wang J., "Enabling Security and Risk-based Operation of Container Line Supply Chains (CLSCs) under High Uncertainties", *EPSRC* (EP/F024436/1 & EP/F024606/1), £562,912; 2008-2011.

**RP 4:** Wang J., "A safety-based fire and rescue management system", *EPSRC* (GR/F041993), £135,751; 2009-2012.

**RP 5:** Wang J., "Weastflows - West and east logistic flows (Weastflows) in the North West of Europe", *EU-Interreg NWE*, €700,000 allocated to LJMU (out of €9m); 2011-2015.

**RP 6:** Wang J., "REFERENCE - Research Network on Flexible Risk Assessment and Decision Science", *EU-FP7* (Ref no. 314836), €384,000; 2012-2016.

**RP 7:** Hu S.P. Fang Q.G., Wang J., "Formal safety assessment of vessel accidents in confined waters", Shanghai Municipal Education Committee & *Shanghai Leading Academic Discipline*, ¥3m (£300,000); 2013-2018.

**RP 8:** Yang Z.L., "ENRICH: EC-China Research Network for Integrated Supply Chains", *EU-FP7* (Ref no. 612546), €590k; 2013-2017.

**RP 9:** Wang J., "RESET - REliability and Safety Engineering and Technology for large maritime engineering systems", *EU-Horizon 2020* (Ref no. 730888), €1,427,500; 2017-2021.

**RP 10:** Wang J., "ARCWIND - Adaptation and implementation of floating wind energy conversion technology for the Atlantic region", *EU-Interreg Atlantic Area* (Ref no. EAPA_344/2016), €400,437 allocated to LJMU (out of €3.9m); 2017-2021.

**RP 11:** Wall A., Wang J., Jenkinson I., "KTP with Risktec Solutions Ltd. To develop risk and safety assessment materials", *DTI*, £123,000; 2008-2010.

**RP 12:** Wang J., Loughney S., "A decision support system" and "Collision Risk Management for Offshore Installations and Ship/Platform Collision", *UK HSE* (Ref no. D3474 & PRJ1205), £120,000; 2001-2007 & 2017-2018.

## 4. Details of the impact

RAIDS and its associated supporting models has influenced industrial practice and facilitated the shaping of a goal-setting regime, now increasingly used in maritime systems design and operation. Examples of industry adoption of the risk-based decision support tool follow:

1. The HSE has used the tool to improve offshore safety through a reduction in the number of collisions between offshore installations and vessels [ROs 3, 4; RPs 1, 2, 12]. The support tool currently benefits more than 184 offshore oil and gas installations on the United Kingdom Continental Shelf (UKCS). The research has directly led to the development of HSE guidance on avoiding offshore installation-ship collisions and improving the current capabilities of equipment able to warn of a potential collision - using Marine Radar (on Standby vessels or installations), Automatic Radar Plotting Aids, Radar Early Warning systems, Automatic Identification System (AIS) radio navigation and Vessel Traffic Monitoring Systems (VTS). The three relevant HSE guidelines produced by LJMU in collaboration with HSE are: 1) *Effective collision risk management for offshore installations*, HSE Book, 2019, 200 pages; 2) *Ship/Platform collision incident database (2015)*, HSE Books, 2019; 3) *Collision detection on the UKCS*, HSE Books, 2019. 184 offshore oil and gas platforms on the UKCS and 1,327 worldwide have benefited from these guidelines since 2019 [Source 1]. Benefits to the offshore oil and gas platforms have included cost savings from the reduced risk of the demolition/removal of damaged installations after a collision, environmental clean-up and potential commercial costs associated with loss of contracts and business reputation. 14 ship operators including Swire Group, Tidewater, Fletcher Shipping and Subsea7 have benefited from the guidelines. Anchor-handling tug supply vessels, platform supply vessels, multipurpose supply vessels, emergency response/standby and rescue vessels, crew vessels and chase vessels run by these operators have used the guidelines to *"reduce the risk of a collision. In total, 500 offshore support vessels operated by these companies have used the guidelines in their enterprises"* [Source 1]. The guidelines have provided the HSE with an indication of the effectiveness of the regulatory regime. They have been used to inform new HSE developments such as the 'Walk to Work (W2W)' and multi-agency incident response guidance. The guidelines have *"provided offshore stakeholders with an enhanced awareness of both incident occurrence and the regulatory oversight; and have assisted in the reduction of potential collisions and hence helped maintain the risk control options necessary to prevent the loss of life"* [Source 1]. 10 other countries, including Ireland, have also benefited from this research, since they monitor ongoing activities on the UKCS and often duplicate the UK regulatory regime for their own use. Many large offshore operators such as BP and Shell are international operators with their own corporate standards which are then applied locally. They have used the research findings to benchmark themselves against the collision data and looked at ways of detecting potential collision risk as part of mitigation measures [Source 1].
2. The risk-based decision support tool has led to the development of a Risk-Based Verification (RBV) framework for offshore installations [RO 5; RPs 2, 4]. The RBV framework has *"helped duty holders effectively implement the verification process and guided Independent Competent Persons (ICPs) to evaluate the risk associated with safety critical elements"* [Source 5.2]. Lloyd's Register has adopted the tool to facilitate the RBV certification process for offshore oil and gas rigs, which is a mandatory process within the UKCS. Since the introduction of the EU Offshore Safety Directive in 2014, other countries including Cyprus, Ireland, Brunei and Nigeria have adopted this regime. 40 duty holders (owners) including BP, and 250 fixed offshore oil and gas installations have benefited from the work as it has identified

the gaps in the verification process, as well as proposed solutions, such as a toolkit for duty holders/independent verification bodies and the introduction of a proactive verification process. Direct beneficiaries have been the offshore workforce, benefiting from a root cause analysis of the degraded Safety Environmental Critical Elements (SECEs). The RBV framework has been used to identify, and systematically analyse major accident hazards/SECEs, directly leading to a reduction in the cost of verification (10% estimated by Lloyds Register) [Source 2].

3. The risk-based decision support tool [RO 1; RPs 3, 6] has been used in Shell Global Lubricants' planned maintenance system using lubricating oil condition monitoring techniques, benefiting 1,000 ships with tonnage ranging between 5,000 and 250,000 tons. Ship operators' lubricating oil has been monitored in order to take appropriate action before the ship's machinery system breaks down. Industry analysis has indicated that the Return on Investment for lubricating oil analysis, incorporating the safety-based support system, is approximately 14 times. The efficient marine planned maintenance system has been used for robust improvement and management, especially in situations where conventional planned maintenance techniques cannot be implemented with confidence due to data deficiency. The business benefit has been very significant in terms of: 1) the direct revenue from the LubeAnalyst service (over $10m each year since 2016); and 2) the additional lubricants business as a result of being able to offer innovative services (over $100m each year since 2016). It has also led to the development of new strategic partnerships in marine lubricants between Shell and a number of its clients [Source 3].
4. The research has been instrumental in the development of a new engineering safety training approach for high-risk industries, which includes the marine and offshore sectors (mainly in the Middle East region), initially through a two-year KTP project with Risktec Solutions Ltd [RO 6; RP 11]. Risktec Solutions Ltd is a global specialist in risk management consulting, software and risk management training, helping clients manage health, safety, security, environmental and business risk. This KTP project was assessed as "Outstanding" by the KTP Grading Panel in 2010, and selected as the best Knowledge Transfer Partnership in the North West in the KTP Regional Partnership Awards 2011. A novel training approach based on the risk-based decision support tool was used to develop a series of risk assessment courses [RPs 5, 9]. *"The Risktec training business has generated revenues of over £7.5 million since 2014. An approximate revenue per year is £1.2m. Based on 2019 revenue, the FTE for this new business is approximately an additional 5 FTEs."* Risktec has seen *"positive internal staff development for junior staff. There is a general perception (but not one that is easily measurable) that offering training in addition to the core services has improved Risktec's exposure to new customers and clients through an increased profile. This new training approach has enabled Risktec Solutions Ltd to operate their businesses with a much stronger capacity"* [Source 4]. Risktec has part-funded an industrial lectureship (50%) in Risk Assessment at LOOM since 2014. An industrial MSc. course in risk assessment, managed by Risktec in cooperation with Liverpool John Moores University, has attracted an average cohort of 10 learners each year since 2014. The risk-based decision support tool has been used in more than 10 consulting projects worth £5m to Risktec since 2014 [Source 4].
5. The risk-based decision support tool has been used in the design of Alterations and Additions (A&As) for vessels of the Royal Fleet Auxiliary (RFA) since 2016 [RO 6; RP 6], specifically in upgrading and updating capability decision-making. The decision-making tool has been employed in 9 ships of the RFA flotilla and 4 ships (Tide Class tankers) in various stages of completion, trials and commissioning since 2016. The risk-based decision support tool has been incorporated in a novel way, through the application of formal decision-making techniques allied to A&A reasoning as an integral part of the 'in-service' Design Control Board (DCB) process for RFA ships. The DCB process is fundamental to the risk-based decisions made by the RFA for A&As, and has led to cost savings in A&As implementation as a result of a 14-26% saving in man hours. The fundamental principles (of A&A implementation) are applicable to surface ships undergoing design change throughout their service life within the Royal Navy [Source 5].
6. Operational policy and regulations for more than 200 large inland vessels have been shaped/modified through the use of the risk-based decision support tool [ROs 1, 4; RP 8] by

the Three Gorges Navigation Authority and Changjiang Safety Agency, China since 2015. This has increased the annual ship capacity of the Three Gorges ship lock by between 5 and 8% since 2015. Over 45,000 vessels carrying more than 100m tons of cargo pass through the Three Gorges each year [Source 6]. Navigation pressure on the Three Gorges ship lock has eased significantly. The enhanced security warning capabilities incorporating the risk-based support tool have utilized fully the supervision and assistance of modern equipment such as VTS, GPS, and CCTV, rationalizing the working procedures and responsibilities of the navigable command, locks, anchorages, *etc*. The effective identification and real-time monitoring of the ship's navigation are strengthened and implemented. As a result, the time taken for ships to pass through the gate has been shortened and the daily operating efficiency of the ship lock has been improved [Source 6].

7. The research into developing a risk assessment-based approach into the assessment of vessel traffic risks at pilotage and in congested waters [RO 2; RP 7], has been used by the Shanghai Pilot Station (SPS) at the Port of Shanghai to improve SPS pilotage safety since 2014. The technical model, with uncertainties in data and validation, of the proposed risk reduction measures has been developed within the risk-based decision support tool, in collaboration with those at SPS [Source 7]. The research has resulted in an annual reduction of pilotage-related vessel traffic incidents/accidents by 8-12% since 2014. The estimated savings from reducing pilotage-related vessel traffic incidents/accidents are £5m per year since 2014. SPS oversees about 5,000 large ships piloted through the Port of Shanghai each year [Source 7].
8. A detailed study of the relationship between pure risk and compliance and its impact on the risk assessment process has been conducted with Siemens Gamesa Renewable Energy Limited since 2017 [RP 10]. *"Ascertaining what effect work-based substance misuse has on the safety and financial performance of business allows for better assessment methodologies and allows an understanding of the true cost and scale of substance abuse in a UK workforce. The control of substance misuse in the workplace has an effect on the company's incident and accident rates"*. The risk-based decision support tool has been used to produce an industrial guideline on drug and alcohol abuse through investigating if the control of substance misuse in the workplace has any effect on the company's incident and accident rates. The guideline has been in use by Siemens, *"already benefited a number of offshore wind farms and has been shared with the offshore wind energy industry body (The G+ Organisation)"*. The drug-related accident rate has fallen by 40% and the incident rate by 58% in 2019 when compared to the 2017 figures. Annual hours saved have increased by 56% when compared with the 2017 data [Source 8].

Evidence of the long-term industrial impact is demonstrated by three prestigious awards to LOOM members from three professional institutions. These include 1) the award for 'Outstanding Contribution to Marine Safety' from the Institute of Marine Engineering, Science and Technology (IMarEST) in 2018; 2) the Royal Institution of Naval Architects (RINA) – Lloyd's Register Maritime Safety award for improving the safety of life at sea and the protection of the maritime environment through novel and improved design, construction and operational procedures in 2018; and 3) "Award for Risk Reduction in Mechanical Engineering" for outstanding contribution in risk reduction of maritime/mechanical systems as the annual winner from the Institution of Mechanical Engineers (IMechE) in 2018. All three awards are given to a member of the global marine community in recognition of a significant contribution to improving maritime safety in the sector annually.

**5. Sources to corroborate the impact**

Source 1: HM Principal Inspector, HSE, UK
Source 2: Surveyor in Charge, Lloyd's Register EMEA, UK
Source 3: LubeAnalyst Leader, Shell Global Lubricants, UK
Source 4: Technical Manager, Risktec Solutions Ltd, UK
Source 5: Manager, Platform Mechanical Systems, MoD, UK
Source 6: Director of Three Gorges Navigation Authority and Changjiang Safety Agency, China
Source 7: Managing Director, Shanghai Pilot Station, China
Source 8: UK & IE Risk Manager, Siemens Gamesa Renewable Energy Limited, UK