Institution: Lancaster University

Unit of Assessment: UoA 10: Mathematical Sciences

Title of case study: Investigating the sinking of the M.V. Derbyshire and the setting of global design standards for bulk carriers using statistical extreme value research

1. Summary of the impact (indicative maximum 100 words)

Research on extreme value methods by Heffernan and Tawn at Lancaster, which proved critical in determining the conclusions of the High Court's investigation of the sinking of the M.V. Derbyshire, also identified that design standards for the strength of hatch covers of ocean-going carriers (bulk carriers, ore carriers and combination carriers) needed to be increased by 35%. This new level was set as a worldwide mandatory standard in 2004. During the REF census period this change has impacted on the design of 1720 new carriers and strengthening for the 5830 in service. There have been no sinkings of ocean-going bulk carriers since the new design standards were introduced in 2004, whereas on past evidence over 100 such sinkings of ocean-going bulk carriers would have been expected in the REF census period.

2. Underpinning research (indicative maximum 500 words)

Research for the MV Derbyshire: 2000

The research for this shipping case study stemmed from an approach by Mr Justice Colman who was presiding over the High Court's Re-Opened Formal Investigation into the sinking of the M.V. Derbyshire in 2000. Tawn was appointed the sole expert to deal with statistical issues. Research was required to estimate the probability of the M.V. Derbyshire incurring excessive wave impacts on its hatch covers in the typhoon when it sank. In particular, a series of estimates were required under different scenarios of the running of the ship.

By drawing heavily on 20 years of research on extreme value methods at Lancaster, Heffernan and Tawn were able to integrate complex data and knowledge into their estimates of the probability of sinking. This information included: hindcast wave data for the time of the sinking, wave impact data from tank studies performed on a replica of the M.V. Derbyshire in a range of wave conditions, engineering knowledge about the state of the vessel and different operating conditions. Heffernan and Tawn derived estimates and confidence intervals of the probability of the ship sinking under a range of operating scenarios. The results gave a clear delineation into the potential causes of the sinking and a formal quantification of the knowledge of the naval architects involved in the investigation (see Heffernan and Tawn, 2003, 2004b).

These modelling approaches required the incorporation of changes in the covariates over the duration of the typhoon that sank the M.V. Derbyshire. The research developed new measures of fit pooled over covariates. Advanced extreme value methods were essential to deriving reliable estimates given that the required wave impact on the ship's hatch cover to have led to the sinking was larger than any derived in the tank studies. Longer running of the tank studies was impossible, so the only way to achieve the required information of the investigation was through extreme value methods. This was the first use of extreme value methods in naval architecture.

Research to set new design standards: 2000-2002

The report of the High Court Re-Opened Formal Investigation in 2000 proposed further study to review the adequacy of the current international design standards for shipping in relation to hatch strength of ocean-going carriers. Heffernan and Tawn undertook all the statistical analysis in that study using tank data supplied by the Netherlands Maritime Research Institute. The data contained wave impacts on the hatch covers and walls for a range of bulk carrier designs and extreme wave conditions. A highly efficient analysis of wave impacts was derived covering all bulk carrier types, including using: extreme value threshold methods; pooling different studies to ensure consistency;

and exploiting joint dependence and stochastic ordering between impacts on the hatch covers and the walls. Resulting estimates of the distribution of extreme wave impacts on these hatch covers and walls were then derived over the range of operating conditions. The details of this modelling are described in Heffernan and Tawn (2001) and Tawn and Heffernan (2001) but with key features of the approaches building on research in Heffernan and Tawn (2004a) and Nadarajah et al. (1998), with the former an Royal Statistical Society discussion paper cited in Heffernan and Tawn (2001) but appearing later.

3. References to the research (indicative maximum of six references)

Key references

Heffernan, J. E. and Tawn, J. A. (2001). Extreme value analysis of a large designed experiment: a case study in bulk carrier safety. Extremes, 4, 359--378.
Heffernan, J.E. and Tawn J.A. (2003) An extreme value analysis for the investigation into the sinking of the M.V. Derbyshire. Appl. Statist. 52, 337-354.
Tawn, J.A. and Heffernan, J.E. (2001). Summary of statistical analysis of the seakeeping model tests, p41-54, Proceedings of the Royal Institution of Naval Architects conference Design & Operation of Bulk Carriers Post M.V. Derbyshire. London.

Other references

Heffernan, J. E. and Tawn, J. A. (2004a). A conditional approach to modelling multivariate extreme values (with discussion). J. Roy. Statist. Soc., B, 66, 497-547.
Heffernan, J. E. and Tawn, J. A. (2004b). Extreme values in the dock. Significance, 1, 13-17.
Nadarajah, S., Anderson, C. W. and Tawn, J. A. (1998). Ordered multivariate extremes, J. Roy. Statist. Soc., B, 60, 473-496.

4. Details of the impact (indicative maximum 750 words)

High Court Re-Opened Formal Investigation of the sinking of the M.V. Derbyshire: 2000

The largest UK ship lost at sea is the bulk carrier M.V. Derbyshire that sank in September 1980 when she encountered a typhoon near Japan. All of the 44 people on board were lost and no mayday was signalled. The reason for her sinking became the focus of a series of reports and investigations that were carried out over the following 20 years and culminating in the £11M High Court Re-Opened Formal Investigation in 2000.

The judge, Colman (2000) paragraph 6.13, described the contribution that the extremes values group at Lancaster made to identify the cause of the sinking as of '*absolutely fundamental importance to the outcome of this Investigation'*. Similarly Hansard (2002) reports '*Professor Tawn concluded from that data that the flooding of both the stores and the ballast tank—even the stores alone—could have produced sufficient loss of freeboard to expose hatch cover No.1 to at least one hatch-breaking wave during the typhoon on 9 September 1980. Therefore, hatch cover strength became crucial, not only to the safety of the Derbyshire, but to all similar vessels, many of which are still navigating the oceans today, thus putting hundreds more lives at risk*.'

High Court Judge calls for new design standards for hatch covers of carriers: 2000

In addition to establishing the likely cause of the M.V. Derbyshire's loss the Re-Opened Formal Investigation's report questioned the adequacy of current regulations governing hatch cover strengths. There were 99 bulk carrier sinkings between 1990 and 1997 with 650 lives lost (http://en.wikipedia.org/wiki/Bulk_carrier) with causes similar to the M.V. Derbyshire.

Hatches were found to represent the most significant point of vulnerability for bulk carriers. Colman (2000, Para 62 of the Summary) stated that the current international standard for hatch cover strength is "*seriously deficient in the context of present day concepts of acceptable safety standards*." He requested further research as a matter of urgency with the work to be carried out by the researchers from the Re-Opened Formal Investigation – specifically by Lancaster's

statisticians, Lloyds Registry of Shipping and the Netherlands Maritime Research Institute. He insisted that this study should carry sufficient authority that the International Association of Classification Societies and the International Maritime Organisation should adopt its findings and thus ensure that new design standards would be mandatory globally.

Lancaster's statisticians identify new design standard: 2000-2002

Funded by the then named Department of Environment, Transport and the Regions, Lancaster's statisticians provided the entire statistical methodology and analysis for the study to develop new design standards and also had input into the design of the study. The research they conducted showed that the strength of hatch covers needed to be increased by 35% from the previous design standards.

Ratification of a new Worldwide Mandatory Design Standard: 2003-2004

It was agreed that the 35% increase in design standard should become internationally accepted. The process of ratifying this change was complex, passing through a series of meetings of the Maritime Safety Committee and the International Association of Classification Societies, as explained below.

Maritime Safety Committee (2002a) shows evidence of progress of the research and Lancaster's contribution. That report documents the committee encouraging the International Association of Classification Societies to rewriting URS21, the design standards for bulk carriers, regarding hatch covers. Maritime Safety Committee (2002b) sets out a framework for the implementation to new and existing ships, with the International Association of Classification Societies updating URS21 in April 2003. The section for URS21 states that its 3rd revision in 2003 came about due to the work undertaken following the Re-Opened Formal Investigation into the loss of the M.V. Derbyshire. The exact changes are a revision of the method for calculating the strength formulation for hatch covers along with the design of the hatch covers themselves. The exact values of this standard vary depending upon the length of the ship, specifically whether it is over, or under, 100m. Finally, the Maritime Safety Committee (2004) adopted the changes and amendment was then made to the SOLAS treaty (an international maritime safety treaty), regulation 7, making this design standard mandatory for U.N. countries.

Quantification of Impact: 2004 onwards

No amendments to the design standard regulations have been made since 2004 and so the global fleet of ocean-going carriers operating through the REF census period follow these new regulations. Specifically, since 1st January 2004, all ship builders that are members of the International Association of Classification Societies must obey these standard requirements and build their ships to this standard. For all 1720 bulk carriers built between 2008 and 12 the strength of hatch covers has been increased by 35% from the previous design standards, and for the 5830 previously built bulk carriers hatches were strengthened and new inspection and maintenance procedures were required (see Intercargo, 2011). Furthermore, from 2004 the International Association of Classification Societies decided they would apply these rules not just to bulk carriers, but to ore carriers and combination carriers as well.

There have been no sinkings of ocean-going bulk carriers since the new design standards were introduced in 2004, whereas on past evidence over 100 such sinkings of ocean-going bulk carriers would have been expected in the REF census period. This drastically improved safety record has provided substantial benefits for the shipping industry, insurers and governments (as illustrated by the parties actively involved in the Re-Opened Formal Investigation of the M.V. Derbyshire).

5. Sources to corroborate the impact (indicative maximum of 10 references)

Colman, Mr Justice (2000) Report of the Re-opened Formal Investigation into the Loss of the M. V. Derbyshire. London: Stationery Office. (Section 6.13 and 6.14, 11, 14 and Appendix 17).

House of Commons Hansard Debates (2002) 25 Jun 2002: Column 195WH

Intercargo (2011) Benchmarking Bulk Carriers, 5th Edition.

Maritime Safety Committee (2002a). Bulk Carrier Model Test Progress Report. 75th Session Agenda item 5.

Maritime Safety Committee (2002b). Report of The Maritime Safety Committee on its Seventy-Sixth Session. Agenda item 5.

Maritime Safety Committee (2004). Report of The Maritime Safety Committee on its Seventy-Ninth Session. Agenda item 3 and Annex 2.

International Association of Classification Societies (2011). Requirements concerning strengths of ships. For information on updates of URS21.