Institution: BRUNEL UNIVERSITY (H0113)
Unit of Assessment: 10 – Mathematical Sciences
Title of case study: Computation of residual risk in industrial explosion protection installations

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

Researchers at Brunel developed a new algorithm for the computation of residual risk in industrial explosion protection (IEP) installations in collaboration with Kidde Plc, which later became a part of UTC Fire and Security (UTCFS), a 57.7 billion USD company. This was the first algorithm clearly quantifying the safety integrity level versus cost trade-off in buying an IEP for the process plant owners. As the cost of such an installation varies from £40,000 to £700,000, quantifying this trade-off was a real unmet user need. A commercial implementation of this algorithm by a UK-based software vendor Optirisk Systems is now being used by the 31 strong sales force of UTCFS worldwide, as their main tool for negotiating the sales of IEP installations.

2. Underpinning research (indicative maximum 500 words)

The research was performed by Dr P. Date and Prof. G. Mitra, both from the Department of Mathematical Sciences at Brunel University, between 2004 and 2012, with the actual impact taking place from 2009 onwards.

The interdisciplinary Centre for the Analysis of Risk and Optimisation Modelling Applications (CARISMA) at Brunel has strong expertise in measurement and optimisation of risk in a wide variety of applications. British explosion protection firm Kidde Plc approached two members of CARISMA, Prof. Mitra and Dr Date, in 2004 to explore ways of measuring residual risk in explosion protection installations. They provided Brunel with a grant of £25,000 per annum for three years.

The research developed a novel and effective computational tool for companies working in industrial explosion protection (IEP) installation sector. Given a plant layout, a contracted protection installation company recommends appropriate locations for explosion protection devices (such as fire extinguishers, optical fire detectors and flame isolation valves) as well as the specific choice of devices to the plant owner. Both the locations and the choice of devices is dictated by many factors such as the level of risk of unwarranted ignition in the process (*e.g.*, due to mechanical friction), the possible intensity of an explosion and the predicted path of flame propagation. The purpose of an explosion protection installation is to minimize the risk to property and personnel in the event of any accident which results in a fire or an explosion. It is always possible to install a 'more expensive' system (*e.g.*, with higher specification extinguishers) which is 'safer' (*i.e.* leaves a smaller risk of an unmitigated explosion). While everybody understands what 'more expensive' means, there was no industry standard approach to measuring what 'safer' means in this context. In other words, there was no standard way for measuring the 'residual risk', *i.e*. the risk of an unmitigated explosion even after installing a protection system, until the Brunel-Kidde algorithm was put into practice for selling IEP installations in 2012 .

Through sustained technical collaboration with researchers at Kidde from 2004-2009, academics at Brunel developed an algorithm for computation of residual risk which was simple enough to explain to the process owners, yet comprehensive enough to address the key issue of quantifying the trade-off between the cost of protection installation and the safety in terms of residual risk. The algorithm, which was published in a peer-reviewed journal in 2009 [1], is based on a directed graph representation of a typical process plant in which nodes represent vessels, edges represent the possible flame paths and the weights on the individual edges represent the flame propagation probabilities. The residual probability of an unmitigated explosion in any one node of the system, for a given explosion protection installation, is calculated by enumerating and adding up probabilities along various flame propagation paths. This algorithm reduces the residual risk to a single number between 0 and 1, with 0 representing a fully mitigated risk and 1 representing a fully unmitigated risk. Then different IEP installations can be compared in terms of this residual explosion probability as a proxy for safety integrity level; the lower this number, the safer the system. As an example, a process plant owner may or may not be willing to pay £5,000 for an extra fire extinguisher on a duct connecting two process vessels, depending on whether it causes the residual risk to go down by a factor of 10 or only by a factor of 2. The key contribution of the algorithm is making this trade-off between the increase in cost of the IEP installation and the corresponding increase in safety integrity level very transparent.

Kidde Plc later became a part of UTC Fire and Security (UTCFS), which is a global company with over 57 Billion USD net sales and over 218,000 employees as of 2013. The new parent company remained committed to the project. The actual impact of research started in 2009, when UTCFS gave a contract to an external software vendor (Optirisk Systems Limited, a London-based software developer) for the development of commercial level software implementing this algorithm. The input data needed for the implementation of this algorithm was produced through extensive laboratory work by a UTCFS subsidiary in Germany in consultation with the Brunel team. The project was completed in 2012.

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

Peer reviewed journal paper

[1] P. Date, R. Lade, G. Mitra and P. Moore, *Modelling the risk of failure in explosion protection installations*, Journal of Loss Prevention in the Process Industries, 22 (4): 492-498, 2009 (2012 impact factor: 1.150, 5 year impact factor: 1.464). http://dx.doi.org/10.1016/j.jlp.2009.03.007

Publications in conference proceedings (in major industry conferences, for user dissemination)

[2] P. Date et al, 12th Symposium on Loss Prevention and Safety Promotion in the Process Industries, Edinburgh, 2007 (three day symposium with around 60 presentations; proceedings published by IChemE).

Grant from industry

[3] £25k per annum for 3 years to Prof. Mitra and Dr Date, from Kidde Plc (2004-2007); internal grant reference available from Management accounts.

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

The cost of IEP installation to the process owner is non-trivial, so offering a transparent mechanism for comparing cost versus safety trade-off is clearly valuable and fulfills a previously unmet user need in the explosion protection installation industry. A typical IEP installation on a process plant costs between £40,000 and £120,000, with some installations costing as much as £700,000. To pay any extra money for a 'better' (or safer) IEP system, the process plant owner needs to know what 'better' means in the context of improved safety. The Brunel-Kidde algorithm, backed by peer reviewed academic research [1] and presented to industrial researchers at multiple international conferences [2], is the first such algorithm which can compare two IEP systems in terms of their safety integrity levels.

Kidde, and later UTCFS, were sufficiently convinced of the value of this research to give a contract worth £75,000 to an external, UK-based software developer (Optirisk Systems Limited, London) to develop a commercial level version of the software (2009-2012). In addition, the company made a very significant and sustained in-kind investment in laboratory experiments to calculate the flame propagation probabilities in typical process plant set-ups. After the handover of the software by Optirisk Systems in 2012, UTCFS trained their entire worldwide sales force of 31 sales operatives in its use. Training for this software tool is mandatory for new sales staff as it is now a standard tool used in IEP sales by UTCFS worldwide. For each candidate protection installation, the software provides a transparent demonstration of the trade-off between the cost paid by the process owner and the reduction in residual risk achieved, and since 2012 it has played a key role in negotiating the sale of explosion protection installations. The value of this work to Kidde/UTCFS can be judged from a letter to Brunel from their Principal Research Scientist. A quote from his letter reads: "We conduct this very complex and challenging business in a competitive and a code compliant environment. Every design ultimately causes us to address and review with our clients the trade-offs between protection options. The envisioned benefit from this work will be to make available at the point of sale a systematic means to assist us and our clients, to make the best decisions in specifying process explosion protection safety measures. Moreover the quantification of the standing residual risk will allow the client to elect a safety integrity level pertinent to their process application."

UTCFS believes that this algorithm is beneficial to the entire industrial explosion protection industry (both for the process plant owners as well as protection sellers). Thus the algorithm was put into the public domain via publications [1]-[2]. In addition, the work has been disseminated through three major international conferences on loss prevention in the process industry which focussed on industry-relevant research. Company users made presentations at two of these conferences, both of which were in or after 2008 (see corroborating sources [S1] & [S2]). The algorithm and its commercial development has given the company a 'first user' advantage whilst, for the process plant owners, the algorithm provides an improved method of risk assessment together with a way of determining the cost of mitigation, which is now becoming widely accepted by both academia and industrial peers.

As the safety installations sold using this algorithm become commonplace, it is very likely that the computation of the residual risk for an IEP system will become a standard practice in the process plant safety industry. Further, it is expected that *some* form of quantification of residual risk, similar to that achievable by Brunel-Kidde algorithm for IEP in process plants, will eventually become mandatory in the practice of buying and selling explosion protection installations in a variety of other sectors (such as passenger aircrafts and offshore oil platforms). Thus the impact of this work has a wide potential reach even beyond the specific industry sector.

5. Sources to corroborate the impact (indicative maximum of 10 references)
Publications [1]-[2] mentioned in section 3 corroborate the impact; in particular, the examples cited in publication [1] are also used for training purposes in UTC Fire and Security.

Presentations by the users, Kidde and UTC Fire and Security:

[S1] R. Lade et al, Hazard XX: Process Safety and Environment Protection, Manchester, 2008 (4 day symposium with 91 presentations; proc. published by IChemE).

http://www.icheme.org/communities/subject_groups/safety%20and%20loss%20prevention/resources/hazards%20archive/~/media/Documents/Subject%20Groups/Safety_Loss_Prevention/Hazards%20Archive/XX/XX-Paper-78.pdf

[S2] R. Lade et al, 11th Process Plant Safety Symposium, Tampa, 2009 (proc. published by AIChE). Abstract available at http://www3.aiche.org/Proceedings/Abstract.aspx?PaperID=145072

Additionally, the following person can be contacted:

Principal Research Scientist, Kidde UK, Thame Park Road, Thame, Oxfordshire, OX9 3RT – a letter of appreciation detailing the value of work to the company has been provided.