Institution: Loughborough University

Unit of Assessment: B11 Computer Science and Informatics

Title of case study: Commercialisation of novel knowledge-based computer tools for process plant design check and hazard identification

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

Loughborough University's (LU) research in the application of artificial intelligence techniques to enhance process safety since 1993 has resulted in novel computer tools that generated the following economic impacts through the creation of a University spinout company, Hazid Technologies Ltd, in 2002:

1) Raised over £1.3m shares capital from investors.
2) Developed research prototypes into state-of-the-art commercial tools for improving process plant safety.
3) Signed a global sales agreement with Intergraph Corporation in 2005.
4) Established a portfolio of major companies around the world as clients.
5) Employs two executive directors, three software developers and three chemical engineers.

2. Underpinning research (indicative maximum 500 words)

In the nuclear, petrochemical, pharmaceutical and other manufacturing industries, process plant safety relies heavily on engineers' ability to identify potential causes in a plant that would lead to hazardous consequences and to address the potential causes adequately in an early stage to prevent accidents. The widely used method for hazard identification in these industries is HAZOP (Hazard and Operability) Study, which is usually carried out during plant design or modification. This is a labour intensive manual procedure in which a team of engineers study the process system diagrams or Process & Instrumentation Diagrams (P&ID) of the plant, postulate possible faults in each plant equipment item that could propagate through the plant and result in a hazardous or undesirable consequence in another item. The potential hazards are noted and action recommended to eliminate or mitigate the hazard and a report of all the work is made. This procedure, invented by ICI, has been used since the mid 1970's and no effective software tool has been developed, except data entry tools, to assist the HAZOP team with the task of identifying hazards. Novel ideas and innovative computer tools are required to improve the efficiency and consistency of HAZOP Studies and design checks and this was provided by Loughborough University from research through projects **G3.1** to **G3.4** listed in section 3.

The PI and CI of the project **G3.1** were Dr Andrew Rushton and Prof Paul Chung respectively. Both were employed by LU throughout the EU grant from 1993 to 1996. Prof Paul Chung was PI of the project **G3.2** and was employed by LU throughout the EPSRC grant from 2001 to 2004. Prof Paul Chung was the Supervisor of the projects **G3.3** and **G3.4** and was employed by LU throughout the two EPSRC EngD studentships from 2004 to 2008 and 2006 to 2010 respectively.

G3.1 investigated the automation of the time consuming HAZOP Study by utilising the knowledge, and emulating the reasoning, of process and safety engineers. P&IDs are stored in a process-oriented, computable format. Model-based plant equipment behaviour is applied to emulate engineers' reasoning about possible causes and how they propagate through a plant resulting in hazardous consequences. The research prototype *HAZID*, resulted from **G3.1** described in **[3.1, 3.2]**, demonstrated that the intensely qualitative HAZOP Study could be computerised to generate the HAZOP results automatically in advance for the HAZOP team to discuss at their HAZOP Study meetings.

Projects **G3.2** and **G3.3** were carried out to extend the ideas of automated hazard identification in continuous plants to batch plants. The research extended the consideration of hazards, due to causes of deviation from steady state, to deviation due to operation errors in batch mode. The state-based approach is described in **[3.3, 3.4]**.

Finally, investigation into automated design checks and automated generation of SAFE charts was carried out by project **G3.4** and the results are reported in **[3.5]**.

In addition to publishing the research findings, and giving seminars and conference presentations, the underpinning research led to Prof Chung being awarded two Invitation Fellowships from the Japan Society for the Promotion of Science (JSPS) to visit Japan in 2001 and 2012.

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

3.1. McCoy, S.A., Wakeman, S.J., Larking, F.D., Jefferson, M.L., Chung, P.W.H., Rushton, A.G., Lees, F.P. and Heino, P.M. (1999), HAZID: A Computer Aid for Hazard Identification: 1. The STOPHAZ Package and the HAZID Code: An Overview, the Issues and the Structure, *Process Safety and Environmental Protection*, 77(6), 317-327. DOI: 10.1205/095758299530242

3.2. McCoy, S.A., Wakeman, S.J., Larking, F.D., Jefferson, M.L., Chung, P.W.H., Rushton, A.G., Lees, F.P. (1999), HAZID: A Computer Aid for Hazard Identification: 2. Unit Model System, *Process Safety and Environmental Protection*, 77(6), 328-334. DOI: 10.1205/095758299530251

3.3. McCoy, S.A., Zhou, D. and Chung, P.W.H., (2006), State-based Modelling in Hazard Identification, *Applied Intelligence*, 24(3), 263-279. DOI: 10.1007/s10489-006-8517-4

3.4. Palmer, C. and Chung, P.W.H. (2009), An automated system for batch hazard and operability studies, *Reliability Engineering and System Safety*, 94(6), 1095-1106. DOI: 10.1016/j.ress.2009.01.001

3.5. An, H., Chung, P., McDonald, J. and Madden, J. (2009), Automated cause and effect analysis for process plants, *AIDIC Conference Series*, 09, 9-18, DOI: 10.3303/ACOS0909002 (A selected paper from ICheaP-9, Rome 10-13, June, 2009 for publication in the conference series).

Grants

G3.1. STOPHAZ (Software Tool for Hazard and Operability Studies), funded by the European Commission under the ESPRIT 3 programme from 1993 to 1996 (http://cordis.europa.eu/). (PI – Dr Andrew Rushton and CI – Prof Paul Chung, both were employed by LU through out the grant from 1993 to 1996).

G3.2. Risk Assessment of Batch Processing Plants, funded by EPSRC (Grant reference: GR/R37531/01) (PI – Prof Paul Chung, employed by LU throughout the grant from 2001 to 2004).

G3.3. Computer-aided hazard identification of batch operations, EngD project funded by EPSRC and Hazid Technologies from 2004 to 2008. (Supervisor – Prof Paul Chung, employed by LU throughout the studentship).

G3.4. Computer-aided applications in process plant safety, EngD Project funded by EPSRC and Hazid Technologies from 2006 to 2010. (Supervisor – Prof Paul Chung, employed by LU throughout the studentship).

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

Pathway to Impact

The advance made in computer-aided safety engineering research described above helped to realise the vision of integrating safety consideration into the mainstream design process and Hazid Technologies Ltd, a University spin-out company, was founded in 2002. The company has raised over £1.3m **[5.1]** investment from venture capitalists, private investors and a county council to carry out the development for commercialisation. From the prototype, considerable work has gone into re-implementing the code to commercial standard. A means of capturing the basic information from the plant P&IDs was developed. The plant equipment knowledge base was greatly enhanced. The fault-propagation engine was refined.

In 2005, Hazid Technologies made a global sales agreement with Intergraph **[5.2]**, a major CAD

system vendor to the process industry. The agreement allowed Hazid Technologies to integrate the safety tools with Integraph's SmartPlant P&ID and for Intergraph to sell the tools as add-on modules to their own SmartPlant P&ID platform.

As development progressed, it became clear that the integration of process information and knowledge-based reasoning allows different novel tools to be developed to automate other safety-related tasks. Further research was carried out **[G3.2 to G3.4]** and new tools to address the difficult problem of HAZOP of batch plants and design checks were developed. The tools are marketed by Intergraph as SmartPlant Process Safety (SPPS) and SmartPlant P&ID Engineering Integrity.

For a number of years, in addition to two full-time Executive Directors, Hazid Technologies employed three software developers and two chemical engineers, with sales support provided by Intergraph. With increased sales and prospects, the company recently took on an additional chemical engineers to provide technical support to clients, thus providing employment for six graduate and mid-career professionals **[5.1]**.

Beneficiaries

The beneficiaries of the commercialisation of the underpinning research can be divided into two groups. The primary beneficiaries are technology vendors. The secondary beneficiaries are the technology users.

In the first group, Hazid Technologies Ltd from 2002 to 2010 benefited from the stimulation of the research and developed a suite of state-of-the-art commercial tools for safety engineering. They also secured a significant amount of investment and created job opportunities. Intergraph Corp, a world-leading supplier of P&ID systems provided a platform for integration and channel for sales. Both of these companies benefit from the sales of the tools and the services they provide. Also, recognising the impact Hazid Technologies is making in the process industry, the world's largest CAD system vendor AutoDesk has admitted Hazid Technologies Ltd into their developer network to integrate the Hazid tools with AutoCAD P&ID **[5.3]** so that the Hazid tools will become part of their portfolio of add-on products, thus benefiting both companies.

The second group of beneficiaries is the global process industry. Current Hazid Technologies clients are major process plant operating companies and engineering companies from around the world, e.g. Arrow Energy (Australia), Bechtel (USA), Chiyoda (Japan), Clough (Australia), Conoco Phillips (Australia), Fluor (USA), HEC (Hyundai Engineering, Korea), IMP (Mexico), KEPCO E&C (Korea), Motiva (USA), Shell (Netherlands) and WorleyParsons (USA) **[5.4]**.

The use of the tools by Hazid is changing the way these companies do design checks and hazard identification. The General Manager of Clough (Australia) states, "SmartPlant P&ID Engineering Integrity will help us to eliminate the manual P&ID checking process for significant time and cost savings. This unique Intergraph solution ensures we maintain high-quality P&IDs, and when handed over to owners, they meet all operational needs of the project. SmartPlant Enterprise solutions have always delivered great value to our projects, and we are fully confident that SmartPlant P&ID Engineering Integrity will drive continued success." **[5.5]**. Intergraph Process, Power & Marine President states, "SmartPlant P&ID Engineering Integrity enables Clough and all other engineering companies around the world to leverage intelligent P&ID capabilities, delivering tremendous value to owner operators when handing over engineering deliverables for enhanced safety, quality and productivity of projects across industries." **[5.5].**

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

The following sources of corroboration can be made available at request:

5.1. Letter from Chair of Board of Directors of Hazid Technologies Ltd confirming investment and employment figures

5.2. Intergraph press release about signing sales agreement with Hazid Technologies Ltd: http://www.intergraph.com/assets/pressreleases/2005/3831.aspx

5.3. AutoDesk article, Process Safety: A New Approach using AutoCAD P&ID as the Data Link, p5-6:

http://autocad.autodesk.com/ama/orig/plant/Process_Safety.pdf

5.4. List of Hazid Technologies clients from Chair of Board of Directors of Hazid Technologies Ltd.

5.5. Integraph press release about Clough signed agreement to use Engineering Integrity http://www.intergraph.com/assets/pressreleases/2013/03-20-2013.aspx