Institution: Loughborough University (LU)

Unit of Assessment: UoA 11 – Computer Science & Informatics

Title of case study: Ensuring safety in the chemical industry through automated design checks and immersive VR training

Period when the underpinning research was undertaken: 2005-2012

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:
Prof Paul Wai Hing Chung	**Chair in Computer Science** **Emeritus Professor**	**Nov 1991 – Sep 2018** **Dec 2018 - present**

Period when the claimed impact occurred: 2014 – 2020

Is this case study continued from a case study submitted in 2014? N

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

Accidents in the chemical industry are rare. However, a single accident can result in a dramatic loss of lives and revenue, and cause damage to the environment. Research at Loughborough University into improving practices to maintain safety underpinned the development of prototypes for checking chemical plant designs. These prototypes were further developed and commercialized via a spin-out (Hazid Technologies) and, along with a novel immersive VR system architecture for training plant operators, have **ensured safety** in the chemical industry via the following impacts: a) Increased use of the tools and services provided by the spin-out as evidenced by the ten-fold increase of annual turnover, from £234k in 2013-2014 to £2.7m in 2019-2020, and b) Improved the professional skills of global energy company BP's field and control room operators, via the adoption of our VR training solution at multiple worldwide sites.

2. Underpinning research (indicative maximum 500 words)

Safety and accident prevention are of paramount importance throughout the whole chemical plant lifecycle. At the design stage, plant safety relies on expert engineers applying hazard identification methods to remove from the design any potential operational problems and rigorously checking the design against national and international standards. At the operational stage, plant safety is through training, providing operators the skills and experience for safe operation and tackling plant malfunction.

Carrying out design checks and hazard identification is labour intensive. The research by Prof Chung, funded by an EPSRC grant and two EngD studentships, funded by EPSRC and industry, on ensuring the safety of chemical plant design focused on two areas. The first investigated the application of state-based reasoning, plant modelling and structured representation of operating procedures to automate hazard identification of chemical plants **[R1, R2]**. The resulted prototypes take as input a digital format of the Piping (or Process) & Instrumentation Diagrams of a plant, and the associated process information and operating procedure, e.g., start-up, then generates the study results automatically, taking into consideration unintended operation and deviation from steady state. The second area investigated automatic design check by encoding clauses from design standards, using examples from ISO 10418. Research issues addressed include knowledge representation and analysis of plant configuration. A prototype tool for design checks and cause effect analysis was created **[R3]**. Again, this tool inputs digital information about the plant design and generates the results automatically.

For operation and maintenance, VR technology promises benefits for operator training, particularly in shop floor manufacturing for practising task sequences. However, there had been little take up in the chemical industry because training for task sequences, as in assembly tasks, is of little value. A virtual chemical plant is of no use if the plant's response to operation or maloperation does not correspond to the changing process conditions in real time. As part of a €9m EU funded FP6 Integrated Project, Prof Chung investigated the creation of a VR platform that would provide realistic responses in the chemical plant setting. This resulted in a network-based system architecture that facilitated flexible integration of application modules to build VR training systems **[R4]**. For example, a process simulator module would provide realistic plant response in real time (e.g., changes in temperatures) and a rule-based module would detect landmark situations (e.g., ignition points) to initiate events like fire. Maloperation and emergency scenarios can also be created for analysing operator behaviour using the virtual plant **[R5]**. As part of the project a prototype based on the proposed architecture was created, which included a 3D model of an existing plant, a process simulation module, a rule-based module, a control room module, and a gas dispersion module. An experiment was successfully carried out using a gas leak scenario to examine how the field operator and the control room operator, in their different virtual settings, worked together to assess the situation.

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

[R1] 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.

[R2] 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.

[R3] An, H., Chung, P., McDonald, J. and Madden, J. (2009), Automated cause and effect analysis for process plants, Chemical Engineering Transactions, Vol 17, pp1281-1286. DOI: 10.3303/CET0917214.

[R4] Xiaolei Shang, P. Chung, J. Fry, L. Vezzadini, M. Colombo (2009), How a process simulator and a rule-based system contribute to virtual reality applications for process safety, Computer Aided Chemical Engineering, Vol 26, pp435-439. DOI:10.1016/S1570-7946(09)70073-2.

[R5] Loupos K., Vezzadini L., Hoekstra W., Salem W., Chung P., Bimpas M. (2007) VR HF and Rule-based Technologies Applied and Combined for Improving Industrial Safety. In: Stephanidis C. (ed) Universal Access in Human-Computer Interaction. Ambient Interaction. UAHCI 2007. Lecture Notes in Computer Science, Vol 4555. Springer. DOI:10.1007/978-3-540-73281-5_73.

The body of research was funded by competitively-awarded grants: an EPSRC grant (GR/R37531/01) entitled Risk Assessment of Batch Processing Plants from 2001 to 2004, a European Commission Integrated Project grant (Grant agreement ID: 515831) under the FP6 programme from 2005 to 2010, with the title *VIRTHUALIS (Virtual reality and human factors applications for improving safety)* (https://cordis.europa.eu/project/rcn/75752/factsheet/es). VIRTHUALIS was one of the largest EC funded research projects at the time, with €9m contribution from the Commission and an overall budget of €12.8m.

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

Ensuring safety in chemical plants begins during the *design phase* of the plant, where methodically and carefully carried out design checks play a key role. Ensuring safety during the *operation phase* relies on the professional skills of the field and control room operators. As described in Section 2, Loughborough's research into safety practices encompasses both these aspects and impacted on safety in chemical plants as follows:

a) Increased adoption of automated design check and hazard identification tools

With accident prevention as the driver, in the past few decades progress has been made in creating engineering standards and hazard identification methods to reduce the risk of accidents happening. However, carrying out design checks and hazard identification studies is labour-intensive and expensive. As a pathway to current impact, we reported in REF2014 that our University spin-out company, Hazid Technologies, was founded to reimplement the prototype computer tools **[R3]** for automated design checks and hazard identification into two products: Engineering Integrity (the design checker) and Process Safety (the hazard identification tool). The deployment of the tools ensures a high design standard, thus reducing the risk of accidents. Fortunately, accidents in the chemical industry happen very rarely due to the quality of design standards that are in place. Because industry does not publicise 'non-accidents', the value and impact of the tools in loss prevention cannot be quantified directly. However, it can be demonstrated by the worldwide industries' purchase and adoption of the tools and services provided by the company.

The Chairman of Hazid Technologies Ltd, commented on the company's recent growth:

> "*Since 2014 the company continued developing, selling and servicing its innovative software tools and the company has grown tremendously. The annual turnover for the financial year 2013-2014 was £234K and the annual turnover for 2019-2020 was £2.7m. From employing 8 people, it now has 16 employees."* **[S1]**

b) Improved the professional ability of BP's field and control room operators via VR training

Our research created a VR solution for team-wide operator training in a safe environment with realistic response for all plant conditions **[R4, R5].** As another way to **ensure safety** in the life cycle of a chemical plant, BP identified the need to train plant operators. Even with a well-designed chemical plant that meets design standards, accidents can occur due to poor maintenance, operation error and component failure. While training is essential, experience of occasional operations and handling component failures cannot be gained easily. For example, plant shut down happens only once a few years for full maintenance, as it is costly due to loss of production and revenue. To address the need for training, BP invested in a development project led by Prof Chung at Loughborough University, to partner with Igloo Vision, a world leader in immersive VR technology, to enhance the training facility based in BP's chemical manufacturing site in Hull.

Adopting the VIRTHUALIS' project's network-based modular integrated system architecture **[R4, R5]**, a proof-of-concept facility was developed and installed in 2014/15. It integrated a 3D virtual version of an existing asset in the Hull site, a process simulator and a control room simulator to provide realistic training experience. Previously, the chemical industry had not taken up VR training, which had been limited to plant walkthrough and practising ordered sequence of tasks.

However, the significance of our development was recognised in 2015 by the IChemE, as the project was among the finalists for two IChemE Global Awards in the categories of *Process Safety* and *Education & Training* **[S2, S3, S4]**. The project received the accolade of *Highly Commended* in both categories **[S4, S5, S6].** The Operations Coach at the BP European Acetyls site in Hull commented on the new facility:

> *"This exciting facet has the ability to link to the traditional DCS simulator thus enabling us for the first time to carry out bi-directional training and assessment activities, and the ability to assess the competence of the whole shift team. We see this as the future for simulation going forward, providing similar opportunities throughout the BP group performing a variety of safety critical tasks."* **[S2]**

The Engineering Product Owner at BP remarked on the further development after the success at the Hull site:

> *"BP commissioned Igloo Vision to implement further installations at bp sites around the World, including Houston USA, Sunbury UK and Tangguh Indonesia. bp also developed mobile solutions that can be rapidly deployed worldwide."* **[S3]**

> *"The installations in bp are considerable investment by us to further enhance our operator training capabilities"* **[S3]**

To what extent the deployment of the novel VR training solution in industry has impacted on accident prevention cannot be quantified as explained earlier. But,

> the installations *"are regularly used to train many 10's of BP plant operators, apprentices and graduates worldwide and is expanding. The VR training solution provides the operators with vital experience of e.g. site and situational awareness, managing occasional operations and handling component failures and outcomes that cannot be gained so easily otherwise."* **[S3]**

Beyond the impact on BP's operators, the research has stimulated the market for similar systems.

> *"In addition, the work helped lead to commercialisation of these kind of software systems from companies such as TSC Simulation and others."* **[S3]**

For example, Igloo Vision's Head of Marketing commented in November 2020 that:

> *"Igloo Vision worked with TSC Simulation Centre, a SME that specialises in process simulations, to provide an installation at Loughborough University for training Chemical Engineering students so that they can have the experience of operating a 'real' plant."* **[S4]**

Since then, TSC Simulation has expanded into this space to enable students at other institutions to develop their professional skills in safety-critical work. TSC Simulation indicated that:

> *"We have blended our simulation capability with one of the latest game engines to create our Interactive Virtual Plants for Universities, Colleges and Training Centres.*
>
> *We have created fully functional Virtual Plants that allow students to interact with and monitor a full size process plant from their computer chair. Each model has a control room and 3D screen which are connected together by our mathematical model."* **[S7]**
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> *"The TSC Interactive Virtual Plant system is now being used in Universities, Colleges & Training Centres around the world, including Loughborough University, University of Hull, Forth Valley College, and BP Training Centres worldwide."* **[S7]**

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

S1 Hazid Technologies testimonial from the Chairman, 23rd November 2020.
S2 BP Video Full Transcript featuring Manufacturing Trainer and Operations Coach, 2015.
S3 BP testimonial from Engineering Product Owner – Tools & data, 14th January 2020.
S4 Igloo Vision testimonial from Head of Marketing, 23rd November 2020.
S5 IChemE Global Awards Certificate 1, 2015.
S6 IChemE Global Awards Certificate 2, 2015.
S7 TSC Simulation website extract, January 2020.