Emerald International Journal of Disaster Resilience in the Built Environment

Virtual Training Environments for Major Incident Response Planning in UK Gas Infrastructure

Journal:	*International Journal of Disaster Resilience in the Built Environment*
Manuscript ID	IJDRBE-01-2017-0007.R3
Manuscript Type:	Research Paper
Keywords:	Major Incidents, Emergency Response Planning, Gas Infrastructure, Virtual Training Environment, Multi-Agency Response, Emergency Response Training

Virtual Training Environments for Major Incident Response Planning

Purpose

An evaluation of a virtual training environment for testing UK gas pipeline emergency response plans.

Approach

Interviews, observations and desk research were used to identify current methods for testing plans. A virtual training environment was developed and evaluated with industry experts using participatory design techniques. Key themes relating to both the current methods for testing plans and for a virtual training environment were identified using thematic analysis.

Findings

Improved training performance, remote participation and evidence of decision testing are benefits a virtual training environment can bring to current practice. It is suggested that a virtual training environment can enhance, rather than replace the current process of testing emergency response plans.

Research limitations

Analysis of the virtual training environment being used to test plans in a live context would give further ecological validity to the findings. A study of the prototype used to test plans for incidents involving sectors outside the gas industry would further validate the findings.

Originality

The application of a virtual training environment to facilitate testing plans and the decision making processes for major incidents involving high-pressure gas pipelines and storage sites, is yet to be documented. This paper contributes to the literature by documenting the decision making process and evaluation of a virtual training environment for testing plans in this context.

Keywords: Emergency Response Planning, Major Incidents, Gas Infrastructure, Virtual Training Environment

Classification: *Research Paper*

Introduction

Failure in gas infrastructure can impact significantly upon individuals, communities and the environment (Berg et al., 2017; McDermott et al., 2017; Hendrick et al., 2016; Adgate et al. 2014). Large scale incidents requiring a multi-agency response from emergency organisations demand careful planning to mitigate their impact. UK pipeline providers are legally bound to comply with UK legislation to prepare for major incidents by testing and reviewing plans every three years (Control of Major Accident Hazards 1999; Pipeline Safety Regulations 1996). Plans are currently tested using paper-based table-top role play exercises. The application of a Virtual Training Environment (VTE) for facilitating the testing of plans and decision making processes for incidents involving high-pressure gas pipelines and storage sites is yet to be documented. This paper documents the design process and evaluation of a VTE for testing the plans of a UK gas pipeline provider to satisfy the Control of Major Accident Hazards 1999 (COMAH) regulations.

The legislation and current methods for testing emergency response plans are reviewed. VTEs as a platform for emergency response training are explored. A participatory design approach to the research methodology is described. Observations of paper-based table-top exercises are documented. The design and evaluation of a VTE prototype for testing emergency response plans is presented and the findings discussed. This is a study of the UK gas industry's emergency response planning strategies but the findings are relevant to other emergency response planning contexts.

Emergency Response Planning in UK Gas Infrastructure

UK legislation necessitates organisations considered at risk of incidents requiring a multi-agency response, plan and prepare for such incidents (Control of Major Accident Hazards 1999, Pipeline Safety Regulations 1996). COMAH legislation places a requirement on organisations (COMAH Operators) to test and review plans for sites bound by the legislation (COMAH sites), every three years through simulation exercises. Exercises serve to test plans and support development of incident response staff competencies (Cabinet Office, 2010). The two main methods currently used

for testing plans within the UK gas pipeline industry are table-top paper-based workshops and live role play (Cabinet Office, 2010). The paper-based method is investigated in this paper.

Exercises are made up of incidents involving scenarios relating to a COMAH site. Throughout an exercise participants are required to make scenario response decisions. Information such as site maps, pipeline and weather data are provided to support decisions. Participants at different levels of the incident command structure, representing organisations that would respond to incidents involving the assigned COMAH site are expected to attend the exercise (Salmond et al., 2011, Health and Safety Executive, 2010). The incident command structure has three levels: Gold operating at a strategic level, Silver at tactical and Bronze at operational. Exercises can be time consuming, requiring several months of planning to coordinate availability of appropriate staff (Home Office Publication, 1998). Often participants come from geographically dispersed agencies presenting logistical challenges relating to the cost of organising and attending exercises (Gamberini et al., 2015; Seater et al., 2015; McGrath et al., 2005), and for site and required personnel availability (Lalonde and Roux-Dufort, 2013; Campbell et al., 2008; Home Office Publication, 1998).

The face to face approaches of paper-based workshops bring benefits to communication and forging relationships, but fail to test many of the more realistic communication flows required during distributed collaborative emergency response tasks (Eide et al., 2012; Convertino et al., 2011; Li and O'Hara, 2009; Jain and Mclean, 2006; 2005). VTEs provide participants with an incremental gain in knowledge over paper-based approaches for collaborative emergency response tasks (Convertino et al., 2011). The use of VTEs for training in emergency response are considered further.

Virtual Training Environments for Emergency Response Planning Activities

VTEs are used throughout the emergency services to train for firefighting (Gamberini et al., 2015; Williams-Bell et al., 2015; Kinateder et al. 2014; Ruppel and Schatz, 2011), emergency vehicle distribution (Jain and Mclean, 2006; 2005), search and rescue operations (Wang et al., 2013; Kobes et al., 2010), Police incident response (Alison et al., 2013; Smith and Carter, 2010) and uncommon situations such as earthquakes, or terrorist attacks (Albores and Shaw, 2008). VTEs have been shown to enhance emergency response skills (Gamberini et al., 2015; Williams-Bell et al., 2015; Kinateder et al. 2014; Ruppel and Schatz, 2011).

VTEs allow repeated testing of scenarios with alternative strategies preparing responders with a better understanding of what to expect at an incident (Williams-Bell et al. 2015; Ganier et al. 2014; Campbell et al., 2008). Immediate feedback enhances the learning experience (Lee et al., 2005) and training environments that provide feedback and consequences to actions leave users feeling more prepared, with increased confidence for entering live experiences (Williams-Bell et al. 2015; Ganier et al. 2014; Hellier et al., 2011). Visual and auditory cues enhance training in scenarios designed for combat and Police activities (Kinateder et al., 2014; Alison et al., 2013; Smith and Carter, 2010). Visual representations allow the scenario information to be independent of the participant's imagination, allowing responders to make decisions based on what they see without assumption (Kinateder et al., 2014).

Running exercises across multiple locations reduces time and costs associated with co-located exercises (Haferkamp et al., 2011; Jain and Mclean, 2005). The simultaneous training of personnel at different levels of the incident management hierarchy is a benefit of distributed software (Kapucu and Garayev, 2011; Li and O'Hara, 2009; Jain and Mclean, 2006, 2005). Strategic decision making across distributed groups is representative of multi-agency incident response (Li and O'Hara, 2009). Increased communication between responders increases trust and improves team cohesion through shared experience (Eide et al., 2012; Convertino et al., 2011; Jain and Mclean, 2006, 2005). The use of VTEs for the testing of and training in emergency response plans in the UK gas industry is not considered in literature, this study seeks to fill that gap with an evaluation of a VTE prototype.

Research Methodology

A participatory design approach was used to develop and evaluate a VTE with a UK gas pipeline COMAH Operator. Participatory design approaches aim to include end user involvement in the design process whilst seeking to destabilise power structures (Vines et al., 2013). Interviews were held with emergency responders at various stages throughout the study. Two paper-based exercises designed to test emergency plans of the COMAH Operator were observed, handwritten notes were taken from both observations and paper artefacts including scenario information, emergency plans, geographical maps, pipeline and weather data were gathered.

Preliminary Interviews

Semi-structured interviews designed to understand current methods for testing plans were carried out with three COMAH Operator employees (P2, P3 and P7 – see table 1). Some of the interviewees were experienced in developing emergency response plans; others in participating in exercises to test plans and all in responding gas pipeline incidents.

Exercise Observations

'Exercise Cornerstone' involved testing the plans for three different geographically located COMAH sites. Each site was assigned a scenario and group of responders responsible for the site. Each group contained mixed levels of command representing the COMAH Operator, Local Authority (LA), Fire and Rescue Service (FRS), National Health Service (NHS) and Police. Media representatives from the COMAH Operator and Police were also present in the groups.

A fourth group included two exercise coordinators and two Gold command officers. The coordinators were responsible for presenting the scenarios to each group and facilitating the exercise. The Gold commanding officers roamed between groups answering questions relating to Gold command activities. Table 1 shows the participant groupings for the exercise. The whole exercise took place in a single room with each group sat round the table relating to their scenario. The scenarios ran in parallel and took six hours to complete. Three exercise participants (P1, P22 and P16) were interviewed during natural breaks within the exercise using a semi-structured approach to understand how an exercise tests an emergency response plan.

Table 1 Exercise Table Groupings

'Exercise Dragon', held four months after Exercise Cornerstone, tested a plan for a new site. Only one group of responders attended, table 2 describes the participants.

Table 2 Participant's from Exercise Dragon

Participants were invited to join Exercise Dragon at different stages throughout the day, the exercise took six hours and table 3 provides a running order of the activities.

Table 3 Observed Exercise Series of Events

Virtual Training Environment Development

A VTE prototype was developed in collaboration with the COMAH Operator. The requirements were gathered in parallel to exercises Cornerstone and Dragon and development was completed later. Meetings were held between the researcher and COMAH Operator representatives over an eight-month period to capture requirements, test designs and test the prototype. Use case scenarios were developed from the initial interviews with P1, P2 and P7. Six half day meetings were held with P7 to validate and test designs. Paper prototypes were developed from the use cases and tested with P7, P7 was encouraged to amend designs by drawing on the prototypes and adding Post-It notes to demonstrate new workflows or design requirements. A further software prototype (figure 1) was developed using a Wizard Of Oz approach which is a cost effective method allowing users to visualise the system and test workflows with limited functionality (Martin and Hanington, 2012). The researcher did a prototype walkthrough with P7 to demonstrate the system and identify system change requirements.

Figure 1 WOZ Prototype Mock Up in PowerPoint

A fully working prototype was developed from the WOZ prototype feedback. The system was tested iteratively throughout development by P7 and a further two rounds of testing were completed by P5, P6 and P7. Testing was facilitated by the researcher who provided instructions to the testers for completing an exercise to test a plan, each round of testing took half a day. The researcher noted prototype requirements changes flagged during testing and the final version was signed off as completed by P7.

The final working prototype was a client-server solution using .Net Technology. A server was created on a single laptop which hosted exercise data in a Microsoft SQL database, devices with the client software connected to the server via a wireless router. Three key design requirements for emergency planning training environments were incorporated: 1) presenting factors from a real situation in a way that participants are not at risk; 2) collecting data which supports unbiased recording on task activities; 3) using exercise data to support after action activities (Jenvald and Morin, 2004). A 3D visual model of the site used in Exercise Dragon was created in Autodesk's 3DS Max from laser scans, Google map satellite imagery and photographs of the site. The model was animated and overlaid with sound to imitate the sound of a high-pressure gas pipeline leak.

Once signed into the VTE participants wait for a facilitator to select a scenario and begin an exercise. Scenarios can be 3D animations, image or text relating to an incident. Figure 2 shows a damaged pipeline animation overlaid with the sound of a high-pressure gas leak. The system stores participant, exercise and scenario details into a log where each item is recorded with a date and time stamp.

Figure 2 3D Animation Scenario

Participants submit scenario responses within the text area at the bottom of the screen. Time remaining for an exercise is shown with a progress bar across the top of the screen. Responses are recorded in the log then the next scenario is displayed. The facilitator may alter the scenario sequences depending on responses. Participants can communicate with each other via the discussion area on the left of the screen and request resources such as emergency plans, maps, pipeline and weather information. Each message submitted to the discussion area is recorded in the log. Only facilitators have access to resources and can make them available. When a resource is released users receive notification via the discussion area and the activity is recorded in the log. Resources can be viewed by clicking on the resource panel within the resources tab (figure 3).

Figure 3 Map Resource

Exercises complete when the facilitator stops the exercise and declares the incident under control or the time allocated for an exercise runs out and the system declares disaster has struck. The facilitator can print a completed exercise report from the log.

A Comparative Evaluation of the Virtual Environment and the Current Paper-based Method

A participatory evaluation of both the current paper-based approach and VTE for the testing and training of emergency response plans was completed. Table 4 shows the evaluation participants and their attendance at exercises Dragon and Cornerstone.

Table 4 Participatory Design Participants

The evaluation took part in three phases completed over a single day. Participants were given different coloured pens and Post-It notes to use throughout the activities so responses could be captured and analysed according to role, organisation and level of command. Each participant completed a questionnaire to capture further details about their emergency planning experience and opinions of the VTE for testing plans. Each phase of the evaluation is described.

Phase 1 - Capture participant perceptions of the current emergency planning process

For the *first task* participants were invited to write on flipchart paper their opinions of using the paper-based approach to test plans and train for emergency responses. They were then invited to add comments on each other's opinions about the statements written. Further discussion around the comments was encouraged and recorded using a voice recorder. For the *second task* participants were given a timeline showing the incident start and end and asked to write where current approaches failed to test the plan on the timeline stages.

Phase 2 – Capturing the level of experience participants had with using software

Task three required the participants to compile a list of software they had experience in using. Participants were then given Post-It notes and asked to leave comments about their experience with the software listed. They were invited to comment on frequency of use, type of use such as social or work related and whether the experience was positive or negative.

Phase 3 – Capturing the participant perceptions' of using a virtual training environment to test emergency response plans

The *fourth task* required participants to write on flipchart paper their expectations of a VTE for testing emergency response plans. This task was completed before the participants had been exposed to the VTE, only P2 had seen the VTE previously. The participants were instructed to complete an exercise to test a plan using the VTE and document their perceptions of the approach on flipchart paper, again further discussion was encouraged and recorded.

Data Collection and Analysis

The information captured throughout the project was entered into NVIVO (QSR International, 2016). Data included handwritten notes from the exercise observations, the comments recorded on flipchart paper during the evaluation tasks, questionnaire and interview data. Six hours of voice recording from the prototype evaluation was transcribed. Eight questionnaires were completed. Five and half hours of interview data was transcribed. Thematic analysis was used to identify patterns in the data, the results from the analysis are discussed.

Results

Twenty-two categories were applied to the data resulting in three key themes: 1) improved training performance, 2) remote participation and 3) evidence of testing decisions. The results are organised into the key themes and contributing factors are discussed.

1) Improved Training Performance

Realistic response times; feedback and consequences to actions and availability of visual and auditory cues, contributed to improved training performance.

Realistic Response Times

Current methods afford participants too much time to think through scenario responses. One hundred and thirty-two data items were classified in relation to paper-based methods providing unrealistic response times for testing plans. Perceived pressure to make decisions and responding to realistic situations were cited as key issues. P2 describes how paper-based exercises compare to his own live incident experience:

> We bring people to these events, be it live or desktop but it's only a representation…I ended up going to you know when they blew the hole up in Gateshead, when the IRA blew that up, it [paper-based role play] doesn't prepare you for that.

At live incidents responders are required to make decisions more quickly, P36 stated of current methods: “you can never really test it [decision making], you can never really get the same feeling as if it was real”. P27 agreed stating the absence of pressure to make a decision was a problem:

> You’re not under pressure, you’re not under pressure to make a decision…it [paper-based role play] doesn't put you under pressure of that walking round the corner and being confronted with for example a fire. You don't know up until you are actually in that position, how you are going to react and whether you’re even going to remember to pick the phone up and make that call.

All participants agreed the VTE progress bar showing the remaining exercise time increased pressure to make decisions. P2 stated the VTE would provide an: “Opportunity to test understanding and feel pressures exerted from various areas during the management of an incident”.

Feedback and Consequences to Actions

Feedback and consequences to decisions are not currently provided for in paper-based exercises. Six participants agreed that lack of feedback meant procedures or processes were not tested within a

plan. All participants agreed the current method for testing plans was not a good test of competency. Consequences were described as things that could happen as a result of an action, or lack of action. P27 stated:

> If certain things aren't done then that's going to effect the [outcome] you know, so the consequences of you not doing something so for example the consequences of me not putting the road block on the A178, is that members of the public could come down there and then the result is to be involved in the incident somehow. You can actually build [consequences] in [to the virtual environment] for different agencies, consequences of not doing certain things.

The VTE allows exercise facilitators to provide feedback and consequences to decisions made through a range of modalities:

- Visual: 3D models, animations and images.
- Textual: Pre-written scripts or comments via the discussion board.
- Auditory: Pre-recorded animations or sound files.

P16 said the feedback within the VTE "provides an understanding of the various types of incident and allows for checking actions, decisions in a safe environment". All participants agreed the VTE would be good for developing staff competencies in making decisions and applying the plan being tested. All participants agreed having feedback and consequences to actions added to the exercise realism. Sixty items were coded as positive aspects of the VTE that could support realistic training through providing feedback and consequences to users.

Visual and Auditory Cues

Exercise Dragon and Cornerstone largely used verbal and textual information to describe the incident, the lack of visual and auditory cues was highlighted as contributing to lack of realism. P36 stated:

> You know you might turn around and I might say, this is the brief, and I've got in my head exactly what I think everybody's gonna [sic] see, but everyone around this table will see it totally different and make a totally different assumption. They act on their thoughts rather than what I mean. That's not what I wanted them to do, that's [the gas pipeline] blown up.

The participants agreed allowing responders to rely on their imaginations of what they thought was happening at the scene may lead to assumptions. Sound was identified as being a particularly relevant indicator of high-pressure gas pipeline damage, as P27 described:

> I mean what we've got with this exercise in particular is you've got the noise isn't it and you would be wearing protective gear, but in the table-top that didn't come across until one of the fire officers mentioned it but you wouldn't get anywhere near it because you couldn't stand the noise, the consequence of that is that people aren't going to get anywhere near because they could get deaf or even a long term impairment to their hearing…apart from all the other bits it might be first thing that helps better our understanding [of an incident].

P16 stated the VTE would be "excellent for operational people who would actually go into that [an incident]…and for educating people in the consequences of their actions". Fifty-two items were coded against using visual and auditory cues to enhance realism within the VTE.

2) Remote Participation

Users can participate in individual exercises or in a group exercise remotely within the VTE. Remote participation provides resource flexibility for testing plans and training, as participants can attend to other daily tasks during moments of an exercise where their input is not required. Communication flows between organisations and across levels of command can also be tested through remote participation.

Resource Flexibility

Paper-based exercises are resource intensive and come with logistical challenges of identifying site and personnel availability. Hosting co-located exercises incurs costs for site use, travel, personnel time, exercise equipment such as print outs and for refreshment provision. P2 argued paper-based exercises were not cost effective "because I end up paying for the people who attend, so it costs us…different authorities create their plans at different rates…as a business it costs us to participate". The costs were more problematic for the COMAH Operator than for public sector participants. Fifteen items were coded against remote participation supporting resource efficiency.

Testing Communication Flows at Different Levels of Command

Paper-based exercises tend to be co-located activities providing an unrealistic environment allowing responders to communicate freely without elements of disruption, "you can communicate easier in a table-top but onsite there's a lot of distraction" (P8). P27 agreed stating: "unrealistic communication, it [paper-based role play] gives you a false sense of security". The ability to participate remotely is representative of live incident control, with much of the incident being dealt with via an operator in a

centralised command centre conveying incident information between agencies. Participants can join an exercise from any location using the VTE via the internet.

Five participants agreed the VTE would be useful for testing communication flows through different levels of command. Users signing in as FRS Bronze may be presented with detailed incident information, while FRS Silver users may only get notified that an incident had occurred. P8 and P14 both stated the VTE could be used to test incident communication between Bronze and Silver users. Twenty-two items were coded against the VTE supporting realistic communication. Bronze staff participating in exercises from different rooms to Silver was something P2 thought could create tension between levels of command indicative of that experienced at live incidents:

> The other thing I think it would be good for is creating a bit of tension between the operational people and the people back in the command room, because you are getting all these calls wanting an update and its exactly the same as it was five minutes ago.

3) Evidence of Testing Decisions

After a paper-based exercise the facilitator is required to compile a report to meet legislative requirements which includes participant details and makes recommendations for plan change requirements. Decisions tested against the plan are not included in the report, having an audit trail of responses and decisions can provide better understanding of further training requirements. Eighteen items were coded against the VTE being able to demonstrate testing decisions during an exercise.

The VTE logs all scenarios and responses, the log can be compiled into a report for the Health and Safety Executive (HSE) to demonstrate plans had been tested to satisfy COMAH legislation. P36 argued the log would be an invaluable resource for use during live incident inquests. The log could offer justification for decisions made, providing “concise evidence of an exercise” (P27), they had been tested and approved in a training environment. P36 stated:

> It's [the VTE] also got more of an impact for your competency in relation to the individual that's using it and you could produce evidence of their competency or lack of their competency. Which actually could be used in future if you have an incident because they will ask for training records and recent training.

The current paper-based approach is not used for staff to train for incident response. P36 commented:

> You've got additional functionality that would capture things from your organisation's point of view, with decision making that's specific for you that would mean that it's got use in a real event, in that people have already practiced [decisions] before the main event.

The VTE can be used as an extra training resource, allowing staff to run exercises independently and repeatedly to test different scenario responses.

Discussion

The findings demonstrate the VTE can improve responder training for implementing plans, increase resource flexibility and allow decisions to be tested in a training environment. Paper-based exercises allow participants to take a more analytical and consultative approach to response normally associated with the incident recovery phase (Crichton et al. 2005). The perceived pressure to make decisions was reduced during paper-based exercises, this corresponds with existing literature (Chricton and Flin, 2001; Crichton et al. 2000). Gamberini et el. (2015) argue anxiety states can be achieved using VTEs as demonstrated with the progress bar which increased pressure to make a decision, adding realism to testing plans.

The literature review indicated feedback and consequences to actions enable responders to feel more prepared for incidents. The procedures and processes within a plan are not tested during paper-based exercises. Feedback and consequences within the VTE were identified as something that enabled responders to test plan procedures and processes, making them more confident for live incident response.

The VTE audio and visual cues contributed to the exercise realism and to preparing responders for incident response, this supports the literature findings (Kinateder et al., 2014). The visual models allowed everyone to work with the same information and the sound was identified as something that could better responders' understanding of an incident.

The log recorded during an exercise within the VTE was identified as a useful resource for training and for meeting HSE legislative requirements. The automatically-generated audit trail of responses and decisions could be reviewed by exercise facilitators to assess where responders required more training. The log could also be used in response to HSE incident inquests providing evidence of formerly tested decisions.

The findings support the literature around distributed collaboration, and demonstrate that remote participation can curiously improve ecological validity of remote communication flows between levels of command and therefore improve training. Participating in exercises remotely can also remove the excessive time and travel costs associated with co-located paper-based exercises. Performing exercises from distributed locations means personnel can attend to other desk-based tasks during exercises. This is particularly useful during times in the exercise where certain parties are not required to contribute to decisions and is, importantly, indicative of how responders actually perform additional duties during live incident response.

The main costs associated with the VTE are the costs of developing the scenarios to run within the VTE along with the costs of maintaining the software and storing data. The benefits of having an online training repository for operational staff were identified, but a specific cost benefit analysis was not explored. The benefits of using the VTE for co-located and geographically distributed exercises are recognised. The participation of operational staff at a co-located venue is representative of a live incident, using the VTE in this environment allows for both the benefits of co-location such as forging relationships with other responders as well as those associated with the VTE. Remote participation of Silver and Gold command staff simulates live incident interaction; remote participation (not otherwise possible in paper-based exercises) in some cases can also reduce costs associated with participation of staff at this level of command. These cost savings would easily be transferred to support the cost of running the VTE.

Limitations and Future Work

The findings would have greater ecological validity if the *evaluation* was carried out in a live context. Testing the system in other emergency response situations would also allow the broader applicability of the VTE to be explored. Although beyond the project scope, a comparative evaluation of the installation and running cost of the VTE in a live context compared to traditional paper-based approaches would provide further detail regarding the system cost benefits.

Conclusion

An evaluation of a VTE for testing emergency response plans in the UK gas industry has been presented. A background to emergency response planning for UK gas infrastructure has been described. Current approaches to testing plans have been documented. Paper-based exercises bring

many benefits to the emergency response planning process within the UK gas industry, providing opportunities for responders to forge valuable relationships, contributing to improved communications and co-operation at a live incident. Paper-based exercises provide opportunities to think through incident response at a more leisurely pace than live incidents. Organising participants for co-located exercises can be time and cost intensive and is not representative of a multi-agency incident response.

Providing auditory and visual cues, feedback and consequences to actions, remote participation and having audit trails of decisions made and exercises performed, have all been identified as benefits a VTE can bring to testing plans. It is not suggested a VTE should replace current practice, but the benefits it brings can offer enhancement to the current process of testing plans.

References

Adgate, JL, Goldstein, BD and McKenzie, LM (2014) 'Potential public health hazards, exposures and health effects from unconventional natural gas development', *Environmental science & technology*, *48*(15):8307-8320.

Albores, P and Shaw, D (2008) "Government preparedness: Using simulation to prepare for a terrorist attack." *Computers & Operations Research* 35(6):1924-1943.

Alison, L, van den Heuvel, C, Waring, S, Power, N., Long, A., O'Hara, T. and Crego, J. (2013) "Immersive simulated learning environments for researching critical incidents: A knowledge synthesis of the literature and experiences of studying high-risk strategic decision making", *Journal of Cognitive Engineering and Decision Making*, *7*(3):255-272.

Autodesk (2017) "3DS Max", Available at: https://www.autodesk.co.uk/products/3ds-max/overview, Last Accessed: May 2017.

Berg, VI, Petryakov, VA and Brand, AE (2017) 'Analysis the Changes of the NGL Product Pipe Safety in the Process of Operation', In *IOP Conference Series: Earth and Environmental Science* 50(1):012041). IOP Publishing.

Cabinet Office, (2010) *Exercises.* [Online], Available at: http://interim.cabinetoffice.gov.uk/ukresilience/preparedness/exercises.aspx (Accessed: 20th October 2015).

Campbell, BD, Mete, HO, Furness, T, Weghorst, S and Zabinsky, Z (2008) "Emergency Response Planning and Training through Interactive Simulation and Visualization with Decision Support", *IEEE Conference on Technologies for Homeland Security,* MA: Waltham, May 12-13, 2008.

Control of major accident hazards Regulations 1999 (SI1999/743).

Convertino, G, Mentis, HM, Slavkovic, A, Rosson, MB and Carroll, JM (2011) "Supporting common ground and awareness in emergency management planning: A design research project", *ACM Transactions on Computer-Human Interaction (TOCHI)*, *18*(4):22.

Crichton, M, Flin, R and Rattray, WAR (2000) "Training Decision Makers – Tactical decision games", *Journal of Contingencies and Crisis Management*, 8(4):208-217.

Crichton, M and Flin, R (2001) "Training for emergency management: tactical decision games", *Journal of Hazardous Materials*, 88(2-3):255-266.

Crichton, M, Lauche, K and Flin, R (2005) "Incident Command Skills in the Management Industry of an Oil Industry Drilling Incident: A Case Study", *Journal of Contingencies and Crisis Management*, 8(4):208-217.

Eide, AW, Halvorsrud, R, Haugstveit, IM, Skjetne, JH and Stiso, M (2012) "Key challenges in multiagency collaboration during large-scale emergency management", In *AmI for crisis management, international joint conference on ambient intelligence, Pisa, Italy*.

Gamberini, L, Chittaro, L, Spagnolli, A and Carlesso, C (2015), "Psychological response to an emergency in virtual reality: Effects of victim ethnicity and emergency type on helping behavior and navigation", *Computers in human behavior*, *48*:04-113.

Ganier, F, Hoareau, C and Tisseau, J (2014) "Evaluation of procedural learning transfer from a virtual environment to a real situation: a case study on tank maintenance training", *Ergonomics*, *57*(6):828-843.

Haferkamp, N, Kraemer, NC, Linehan, C and Schembri, M (2011) "Training disaster communication by means of serious games in virtual environments". *Entertainment Computing*, 2(2):81-88.

Health and Safety Executive, (2010) *COMAH Competent Authority Workstream 6: COMAH On-site Emergency Planning and Mitigation (Operational Delivery Guide),* [Online]. Available at:

http://www.hse.gov.uk/comah/guidance/on-site-emergency-planning.pdf (Accessed: 2nd December 2015).

Hellier, E, Naweed, A, Walker, G, Husband, P and Edworthy, J (2011) "The influence of auditory feedback on speed choice, violations and comfort in a driving simulation game", *Transportation research part F: Traffic Psychology and Behaviour*, 14(6):591-599.

Hendrick, MF, Ackley, R, Sanaie-Movahed, B, Tang, X and Phillips, NG (2016) 'Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments', *Environmental Pollution*, *213*:710-716.

Home Office Publication, (1998) *The Exercise Planners Guide*, [Online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61087/the-exercise-planners-guide.pdf (Accessed: 23rd October 2015).

Jain, S and Mclean, CR (2005) "Integrated Simulation and Gaming Architecture for Incident Management Training", *Proceedings of the Winter Simulation Conference.*

Jain, S and Mclean, CR (2006) "A Concept Prototype for Integrated Gaming and Simulation for Incident Management", *Proceedings of the 38th conference on Winter simulation*.

Jenvald J and Morin M (2004) "Simulation-supported live training for emergency response in hazardous environments". *Simulation & Gaming,* 35(3):363-377.

Kapucu, N and Garayev, V (2011) "Collaborative decision-making in emergency and disaster management", *International Journal of Public Administration*, *34*(6):366-375.

Kinateder, M, Ronchi, E, Nilsson, D, Kobes, M, Müller, M, Pauli, P and Mühlberger, A (2014) "Virtual reality for fire evacuation research", In *Computer Science and Information Systems (FedCSIS), 2014 Federated Conference on* (pp. 313-321). IEEE.

Kobes, M, Helsloot, I, de Vries, B, Post, JG, Oberije, N and Groenewegen, K (2010) "Way finding during fire evacuation; an analysis of unannounced fire drills in a hotel at night," *Building and Environment*, 45(3):537–548.

Lalonde, C and Roux-Dufort, C (2013) "Challenges in teaching crisis management: Connecting theories, skills, and reflexivity", *Journal of Management Education*, *37*(1):21-50.

Lee, MKO, Cheung, CMK and Chen, Z (2005) "Acceptance of Internet-based learning medium: the role of extrinsic and intrinsic motivation", *Information and Management*, 42:1095-1104.

Li, J and O'Hara, K (2009) "Understanding distributed collaboration in emergency animal disease response", In *Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7* (pp. 65-72). ACM.

Martin, B and Hanington, B (2012) *Universal Methods of Design,* MA:Rockport.

McDermott, V, Henne, K and Hayes, J (2017) 'Shifting risk to the frontline: case studies in different contract working environments', *Journal of Risk Research*, pp.1-15.

McGrath, D, Hunt, A and Bates, M (2005) "A simple distributed simulation architecture for emergency response exercises", *Ninth IEEE International Symposium on Distributed Simulation and Real-Time Applications*, October 10-12, 2005.

QSR International, (2016) NVIVO 11 Pro for Windows, [Computer program]. Available at: http://www.qsrinternational.com/nvivo-product, Last Accessed: September 2016.

Ruppel, U and Schatz, K (2011) "Designing a BIM-based serious game for fire safety evacuation simulations", Advanced Engineering Informatics, 25(4):600–611.

Salmond, P, Stanton, N, Jenkins, D and Walker, G (2011) "Coordination During Multi-Agency Emergency Response: Issues and Solutions", *Disaster Prevention and Management*, 20(2):140-158.

Seater, RM, Rose, CE, Norige, AS, Chang, KC, DiPastina, P and McCarthy, J (2015) "Skill Transfer and Virtual Training for IND Response Decision-Making: Models for Government-Industry Collaboration for the Development of Game-Based Training Tools", Massachusetts Institute of Technology Lexington Lincoln Lab, 5th May 2015, 1208.

Smith, SP and Carter, T (2010) "A virtual environment to test police and public awareness of anti-social behaviour indicators", *International Journal of Police Science and Management*, 12(4):548-566.

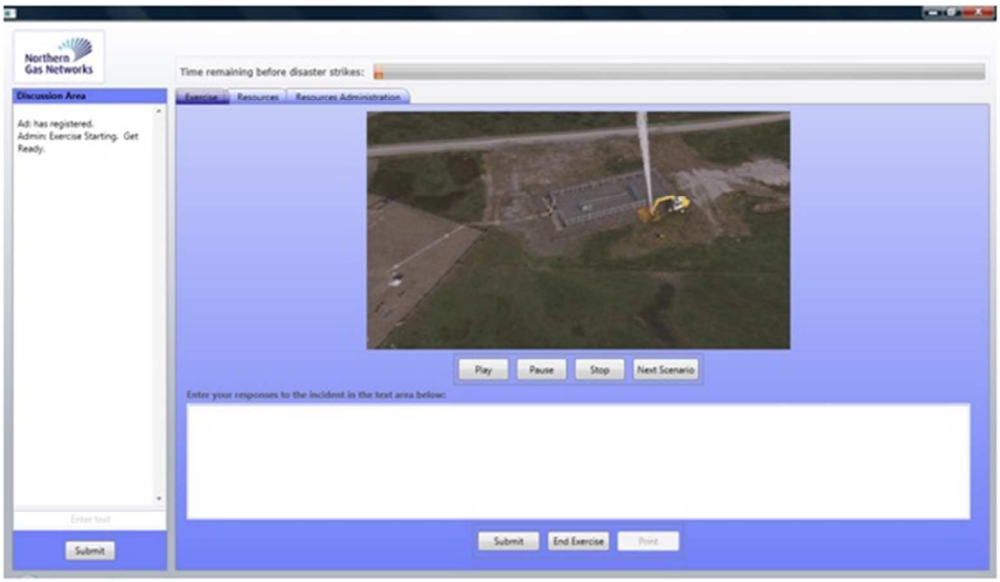
The Pipeline Safety Regulations 1996 (SI1996/825).

Wang, B, Li, H and Rezgui, Y (2013) "Intelligent building emergency management using building information modelling and game engine," ICIC Express Letters, 7(3B):1017–1023.

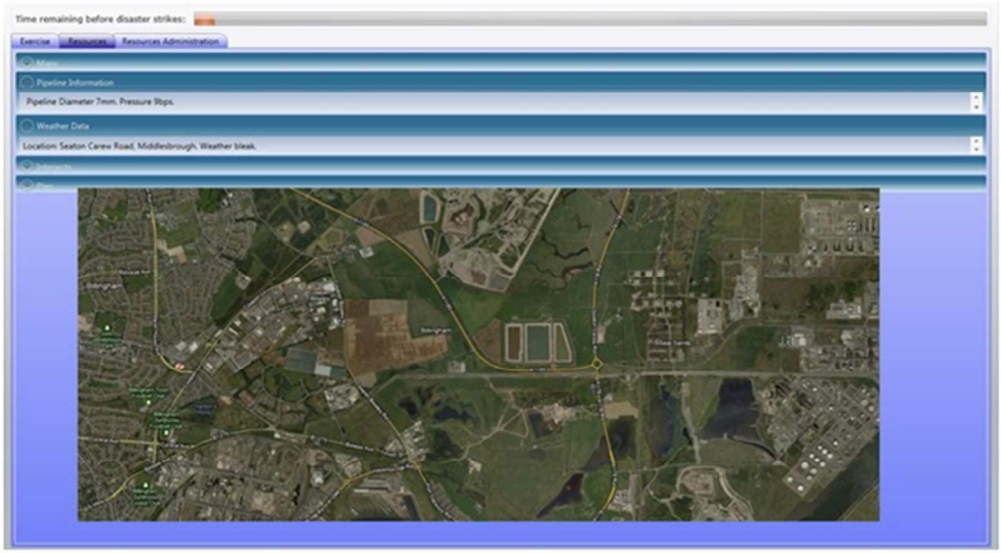
Williams-Bell, FM, Kapralos, B, Hogue, A, Murphy, BM and Weckman, EJ (2015) "Using serious games and virtual simulation for training in the fire service: a review" *Fire Technology*, *51*(3):553-584.

Vines, J, Clarke, R, Wright, P, McCarthy, J and Olivier, P (2013) "Configuring participation: on how we involve people in design", In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (429-438). ACM.

Figure 1 WOZ Prototype Mock Up in PowerPoint



160x92mm (96 x 96 DPI)



160x88mm (96 x 96 DPI)

Table 1 Exercise Table Groupings

Organisation	Table 1 Participants	Table 2 Participants	Table 3 Participants	Roaming Participants
COMAH Operator	P1: Bronze P2: Silver	P3: Bronze P4: Media	P5: Bronze P6: Media	P7: Coordinator (Silver)*
LA	P8: Bronze P9: Facilitator	P10: Facilitator P11: Observer	P12: Bronze P13: Facilitator	P14: Coordinator (Silver)*
FRS	P15: Bronze P16: Observer (Silver)*	P17: Bronze	P18: Bronze	P19: Gold
NHS		P20: Silver	P21: Silver	
Police	P22: Bronze P23: Media	P24: Bronze	P25: Bronze P26: Media	P27: Gold

* Observer and Coordinator participants were not part of the response teams

Table 2 Participant's from Exercise Dragon

Organisation	***Participants***
COMAH Operator	*P1: Bronze* *P2: Silver* *P3: Bronze* *P7: Facilitator (Silver)* *P30: Observer*
LA	*P8: Facilitator (Silver)* *P14: Bronze*
FRS	*P31: Silver* *P32: Bronze* *P33: Bronze* *P16: Observer (Silver)*
NHS	*P34: Bronze* *P35: Bronze*
Police	*P27: Observer (Gold/Silver)** *P36: Silver* *P37: Bronze*

** Gold command sometimes interchanges between Silver and Gold command depending on response requirements.*

Table 3 Observed Exercise Series of Events

Stage	***Activities***
NHS enter	*NHS: listens to 999 call of incident; shown visual mock-up of incident projected on a screen; ask FRS questions regarding the incident; asked to treat COMAH operator facilitator as the injured party. Facilitator makes hand written record of the discussion between NHS and the injured party.*
Exercise start FRS enter	*FRS listen to 999 telephone call of incident. Facilitator asks FRS what their next action would be and records response. FRS take a seat at large table, where further printed information regarding pipeline pressure, incident location, failure drawings and details of the injured party are available. FRS request information such as wind speed and weather data from facilitator, information provided in printed format.*
Police enter	*Police ask FRS and NHS for incident debrief. FRS request information which requires the presence of the LA. LA joins the exercise.*
LA enter	*Discussion between police, FRS and LA. Police declare incident as a major incident.*
COMAH operator enter	*COMAH operator asked to join the exercise. COMAH operator debriefed by police. All participants seated at the table and given time to read the printed information about the exercise and questions. COMAH operator requests further information regarding pipeline data, data provided in printed format. COMAH operator asked to continue their discussions on a separate table.*
Actions & interjects	*Each agency asked to continue discussions within their own group to decide next course of action. Exercise facilitator presents interjects to some of the groups to add complexities to the response.*
Incident under control	*Police calls debrief between agencies, when complete police declare incident under control.*
Break for lunch	*COMAH operator, exercise facilitator and observers from police and FRS Silver discuss exercise outcomes.*

Table 4 Participatory Design Participants

Organisation	***Participants***	***Attended Exercise***
COMAH Operator	*P2: Silver*	*Cornerstone and Dragon*
	P3: Bronze	*Cornerstone and Dragon*
	P30: Bronze	*Dragon*
LA	*P8: Bronze*	*Cornerstone and Dragon*
	P14: Silver	*Cornerstone and Dragon*
FRS	*P16: Silver*	*Cornerstone and Dragon*
Police	*P27: Gold/Silver*	*Cornerstone and Dragon*
	P36: Silver	*Dragon*